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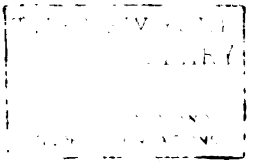

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Charles Proteus Steinmetz.

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OF THE

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OF

ELECTRICAL ENGINEERS.

VOL. XVIII.

1901

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XVIII. JANUARY TO DECEMBER. 1901.

New York, January 9th, 1901.

The 149th meeting of the INSTITUTE, which was organized as a dinner, was held at "The Arena," 41 West 31st Street, this date, and the topic announced for discussion was "Electricity in the Last Century and in This."

The meeting was called to order by President Hering at 9.55 o'clock. The following resolution was unanimously adopted:

Whereas, The Committee on Coinage, Weights and Measures of the House of Representatives has favorably reported by a unanimous vote, bill H. R. 11350, and

Whereas, On account of the entire absence of official electrical and photometric standards and the practical absence of standardizing facilities for electrical measuring apparatus, it is

Resolved, That we, THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, in meeting assembled this ninth day of January, 1901, do strongly urge the Honorable Speaker of the House of Representatives and the Honorable Members of the Committee on Rules to fix an early date for the consideration of this bill so vitally important to the scientific, educational, manufacturing and especially to the electrical interests of the country.

The President then invited Past-President Martin to act as Toastmaster for the evening, and upon his request the following gentlemen spoke upon the topic announced for the occasion: Dr. N. S. Keith, founder of the INSTITUTE, Past-President Arthur E. Kennelly, Past-President Francis B. Crocker, Past-President Frank J. Sprague, and Prof. W. H. Hallock.

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At a Meeting of the Executive Committee, on Wednesday, January 9th, 1901, the following associate members were elected:

Name	Address	Endorsed by
BARR, FRANK ADELBUT	Manager and Electrician Fries M'f'g & Power Co, Winston-Salem, N. C.	C. C. Chesney. A. A. Knudson. Paul Spencer.
BEAUMONT, CHAS. W.	Assistant with Frank B. Rae, 45 Broadway, residence, 223 W. 122nd St., New York City.	Frank B. Rae. J. J. Mahony. W. B. Potter.
BERGENTHAL, VICTOR W.	The Stanley Electric M'f'g Co., residence, 74 Wendell Ave., Pittsfield, Mass.	John F. Kelly. F. A. C Perrine. C. C. Chesney.
CROZIER ARTHUR BERTRAM	Draughtsman and Engineer, Schwarzchild & Sulzberger Packing Co., residence, 1326 East 9th St., Kansas City, Mo.	W. N. Gladson. E. R Weeks. W.E.Goldsboro'h.
DAWSON, JOSIAH	Contractor for Electric Light and Power, etc., Cuba Street Extension, Wellington, New Zealand.	G. Fischer. J.S Fitzmaurice. Arthur J. Hanson,
DOUBT, THOMAS EATON	Professor of Physics and Electrical Engineering, The University of Washington, Seattle, Wash.	N. W. Huggins. R. B. Owens. F. B. Crocker.
GOTSHALL, WM. C.	Electrical Vehicle Co., 46 Fifth Ave., New York.	C. O. Mailloux. Rob. McA. Lloyd, T. C. Martin.
GOUGH, HARRY EUGENE	Assistant in Office Mechanical Engineers, Penn. R. R. Co., 1415 11th Street, Altoona, Pa.	Harold B. Smith. Harris J. Ryan. Fred'k Bedell.
KRUESI, AUGUST H.	Designing Engineer, General Electric Co, residence, 16 Union St., Schenectady, N.Y.	E. W. Rice, Jr. A. H. Armstrong. C. P. Steinmetz.
LISLE, ARTHUR BEYMER	General Representative, Narragansett Electric Lighting Co., Box 1223 Providence, R. I., residence, East Greenwich, R. I.	W. C. Woodward. Louis W. Downes. C. F. Wallace.
MOSCHKOWITSCH, MEERS S.	Machado & Roller, residence, 307 86th St., New York.	H. L. Holbrow. Geo. F. Sever. F. W. Roller.
SCHMIDT, CHAS. J.	In Engineering Department as Telephone Engineer, Milwaukee Electric Railway & Light Co., Construction Department, Milwaukee, Wis.	D. C. Jackson. B. J. Arnold. Max W. Zabel.
SMITH, IRVING WILLIAMS	Electrician Bishop Gutta Percha Co., 420 East 25th St., residence, 5 West 90th St., New York.	H. A. Reed. H. D. Reed. J. W. Lieb, Jr.
VANDERVEEN, ANTHONY R.	Machinist, The South India Railway Co., Holland Road Nyapatam, India.	Jos. Wetzler. T. C. Martin. Geo H. Guy.

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WEBBER, CHARLES EDMOND	Major General with the Institution of Electrical Engineers, as Past-President and Member of Council 17 Egerton Gardens, London, Eng.	S. P. Thompson. Ralph W. Pope. Carl Hering.
WOOD, ARTHUR BRYANT	Assistant Electrical Engineer, The Eddy Electric Co., Windsor, Conn.	H. S. Carhart. H. E. Heath. W. R. C. Corson.

Transferred from associate to full membership.

Approved by Board of Examiners, November 12th, 1900.

LYMAN, JAMES	Assistant Engineer ; Chicago Office, General Electric Co., Monadnock Building, Chicago.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, January 25th, 1901.

The 150th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Hering at 8.15 P. M.

Mr. William J. Hammer, Secretary *pro tem*, announced the election by the Executive Committee of the following associate members:

Name.	Address.	Endorsed by
BARNETT, CARL P.	Draftsman and Engineer, with S. & S. Packing Co., 1326 E. 9th St., Kansas City, Mo.	W. E. Goldsbor'gh. Edwin R. Weeks. W. N. Gladson.
BLAKEMORE, MAURICE NEVILLE	Electrical Engineer, with Westinghouse E. & M. Co., Pittsburg; residence, 306 The Colonial Bldg., Wilkinsburg, Pa.	Chas. F. Scott. W. K. Dunlap. F. L. Hutchinson.
BRANDAO, JULIO VIVEIROS, *C. E.*	Rua Barao do Flamengo 8 Rio de Janeiro, Brazil, S. A.	James Mitchell. Ralph W. Pope. W. J. Hammer.
BROWN, WARREN DAY	Electrical Engineer, the Auto-Electric Co., 61 Elm St, residence, 103 E. 39th St., New York City.	Eugene Griffin. Putnam A. Bates. Arthur Williams.
CHILD, CHARLES TRIPLER	Technical Editor "*Electrical Review*." 13 Park Row, New York City.	J. J. Carty. W. E Goldsbor'gh. Chas. W. Price.
DAVIS, HARRY PHILLIPS	Engineer of Detail Dept., Westinghouse E. & M. Co.; residence, 327 Neville St., Pittsburg, Pa.	Chas. F. Scott. L. A. Osborne. P. A. Lange.
DOWIE, HORACE	Engineering Staff, Crocker-Wheeler Co., Ampere, N. J.	Gano S. Dunn. F. V. Henshaw. E. M. Archibald.

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GILLE, HENRY JOHN	Supt. Elec. Dept., St. Paul Gas Light Co., St. Paul, Minn.	Henry Floy. G. D. Shepardson. Edward P. Burch.
HASKINS, WILLIAM EDGAR	Chief Electrician So. Wks., Am. Steel & Wire Co., 27 Whipple St., Worcester, Mass.	T. Wolcott. Harold B. Smith. Forrest R. Jones.
HOWES, ROBERT	Asst. Supt. of the Light & Power System of Washington Water Power Co., Box 1587, Spokane, Wash.	Samuel Sheldon. A. W. Chapman. H. J. Ryan.
STUART, HARVE R.,	Electrical Engineer, with W. E. & M. Co., Pittsburg; residence, 524 Wallace Ave., Wilkinsburg, Pa.	Chas. F. Scott. Jno. S. Peck. N. W. Storer.

Total 11.

THE PRESIDENT:—The first paper of this evening is by Prof. W. Elwell Goldsborough on "Air-Gap and Core Distribution." Owing to the inability of Prof. Goldsborough to be here, Dr. Sheldon has kindly consented to read an abstract of the paper.

[See page 680, vol. xvii, for paper and discussion.]

The next paper is by Mr. William B. Vansize, "A New Page-Printing Telegraph."

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A paper presented at the 150th Meeting of the American Institute of Electrical Engineers, New York, January 25th, 1901. President Hering in the chair.

A NEW PAGE-PRINTING TELEGRAPH.

BY WILLIAM B. VANSIZE.

The problem of automatically recording telegraph messages in Roman type is one that has fascinated inventors almost from the days of Morse. Royal E. House invented a type printing telegraph, which was in successful operation in this country in competition with the Morse and Bain systems prior to 1857. Many years ago the stock-ticker was perfected, and the Hughes, a tape printing telegraph, and several modifications of it have been employed for a long time with success by various telegraph administrations, chiefly on the Continent of Europe. But it is only within the last year or two, almost at the close of the 19th century, that the problem of constructing a long-distance, high-speed, page-printing telegraph has been solved. A printing telegraph of this kind has recently come to my attention.

It has received the commendation of practical men in the telegraph service, and is believed to be of such simplicity and merit as to win for itself and maintain a position among the apparatus and instruments in constant use on commercial telegraph lines. The arrangement referred to has been devised and constructed by and under the direction of Donald Murray, an Australian journalist, without prior practical experience in telegraph work.

A Retrospect.

Looking back over the last thirty years, a substantial part of which time has been spent in the service of the large telegraph corporations, I can recall but comparatively few arrangements of apparatus which have passed the experimental stage and gone into commercial use. In 1869 there was the well known Morse

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key and spaced alphabet, with the relay and sounder, and in some few instances the embossing register at way stations. In 1872 or 1873, circuits were equipped with balanced receiving apparatus and continuity preserving transmitters for duplex transmission. A little later, reversals of current were used for one set of signals and variations in current strength for another set of signals, affording two transmissions in the same direction. By duplexing this last named arrangement the quadruplex was brought to a more or less satisfactory condition through the efforts of Edison, Jones, Nicholson, Prescott, Gerrit Smith and others. About 1875 there was introduced on the lines of the Atlantic and Pacific Telegraph Company an automatic system of transmission improved by Little and Edison, employing a perforated paper strip at the transmitting station, and a chemically-prepared paper strip to record the Morse characters at the receiving station. Some years later the Wheatstone system was first employed by the Western Union Telegraph Company. Later Mr. Delany's arrangement for distributing a single main line between a number of sending and receiving operators at separated stations was employed on a special line between Boston and Providence. Numerous systems of printing telegraph, recording upon a strip of paper and upon a page have been patented and exploited by corporations organized for that purpose. The Phelps motor printer, in this country, and the Hughes printing telegraph upon the Continent of Europe, both recording upon a strip, have had more or less extensive employment.

It is undoubtedly objectionable to use a perforated strip for transmitting purposes; but when to this is added a received record to be translated, there exist objections which only other merits, as in the case of the Wheatstone apparatus, partially compensate. At the other extreme is the simple Morse requiring no added time interval for translation at either end of the circuit; the operation of transmitting and recording being substantially co-extensive with the time in transit.

Recent Developments.

The later improvements in printing telegraphs have been directed to finding a substitute for the direct manual operation of the key-board and the employment of automatic transmission, like that of the Wheatstone system, by the use of perforated tape. The work of the operators in transmitting messages is

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thus first stored in the perforated tape, produced at any convenient speed, and the automatic transmission may take place at a high and uniform rate, the line and receiving instruments being worked to their full capacity. Another means for overcoming the delay due to direct manual transmission is to divide up the use of the line among several operators, a locking device holding the line for an interval at the service of each in turn. In this case while the speed of the operator may be slow, the total use of the line and instruments is greater than one operator could achieve, working at his highest rate. There are two arrangements of apparatus now receiving attention employing the transmitting tape; that of Charles L. Buckingham, and that of Donald Murray, the latter here under consideration. The French system of Emile Baudot and the American system of Professor Rowland employ an arrangement for dividing the use of the line among several operators.

What telegraph officials really need is the simplicity of the Morse system combined with increased speed of transmission and economy of time between the transmitting customer and his addressed correspondent. Up to the present time nothing has surpassed the Morse for this purpose. We may economize time on the wire by the Wheatstone, by the chemical automatic system referred to, or by the use of Delany's multiplex system; we can provide for a special class of telegraph business by adopting some of the high speed transmitting systems like those contemplated by Professor Crehore, or by Delany's modification of the chemical automatic. For these high speed systems requiring preparation for transmission at one end and translation for delivery at the other end, a demand must be created by the requirements of a class of business to be transmitted and delivered faster than the mail, and somewhat slower than the transit time of the Morse system.

In the recent development of Morse there is an analogy between the contest between armor and armor-piercing projectiles on the one hand and the transmitter and receiver of the Morse code on the other. In the case of armored vessels an increase in the thickness or resistance of the armor has been answered by increased capacity for penetration by the projectile, and vice versa. In the early days the embossing or recording register could easily record the most rapid Morse sender. When receiving by sound it is an effort to keep up with the

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speed of a rapid sender, where the receiver uses pen to record in script. When the typewriter is substituted for the pen, the receiver can more than keep pace with the sender; if we introduce automatic Morse transmission we surpass the power of the human ear to receive and translate to the typewriter. If we transmit mechanically and record mechanically by means of a typewriter we shall have eliminated these human agencies with their limitations, and that is what Mr. Murray has done in a very complete and satisfactory manner.

Before further considering Murray's arrangement I want to assign due credit to my friend Chas. L. Buckingham, who has a marvelously ingenious system in commercial use on the lines of the Western Union Telegraph Company. The received record is made in print on the ordinary telegraph blank; the transmission is by means of a perforated paper strip. It has a maximum capacity of about 100 words a minute on a circuit between New York and Chicago. The circuit can be duplexed to double the stated capacity. Its use, I believe, is successful, and commercially so.

Murray's System—Transmitting Arrangement.

Mr. Murray employs a special alphabet, perforating the transmitting tape with a key-board perforator, having a separate movable lever for each character; each character occupies an unvarying linear space on the tape, and consists of five perforated and unperforated subdivisions of such space. The difference in the number and succession of these subdivisions or perforations imparts the designating characteristics. There are no spaces between successive letters or characters. Either makes and breaks, or reversals can be used in transmitting. It is to this fundamental fact—all letters of the same length—that the success of the system is due. Each letter occupies half an inch on the transmitting tape, and a similar length on the receiving tape. The result is that a comparatively simple transmitting tape perforator worked by an ordinary typewriter key-board is rendered possible; there is no necessity for employing a complicated differential paper feed mechanism to provide for letters of varying length. In connection with the ordinary typewriter key-board there is a group of ten punches, one punching magnet, and one spacing magnet, controlling a motor-driven escapement.

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The Receiving Apparatus.

At the receiving station there is an electro-magnetic perforating device which accurately reproduces the transmitting tape by producing corresponding perforations and spaces. This received perforated tape passes from the receiving perforator into the typewriter operating device. This typewriter operating device consists of five longitudinally reciprocating bars or "combs," 39, Fig. 1, presenting five pointed terminals, 40, to a perforated plate or die, 38. The perforated tape passes between the surface of the perforated plate and the pointed terminals of the bars. The pointed terminals of these bars register respectively with the five holes in the die. The tape is moved along between the die and the pointed ends of the bars step by step, the length of a letter or character at each step, say one-half inch. When perforations in the tape coincide with the pointed ends of the bars and corresponding perforations in the plate and die, and the plate is moved toward the pointed ends of the bars, the bars are or may be separated into two groups; one group is moved longitudinally, corresponding with the unperforated subdivisions of the tape, the other group project through the perforations in the tape and in the die, and are unmoved. Lying over the five bars or "combs" at right angles thereto, are a series of thin metal strips, 41; each strip is mechanically connected with its individual key lever on the typewriter. The upper surface of the five bars first described are notched arbitrarily. These notches are caused to be aligned below any one of the strips under the control of the perforated tape and die; when any one of the strips drops into a groove a motor-driven cam engages it and produces a movement of the typewriter lever. The movement of the die and paper tape and of the typewriter key-lever is produced by motor-driven cams. It will be seen that this mechanism will operate not only a typewriter, but any keyboard machine such as a typesetting machine or linotype. The perforated receiving tape is therefore available for setting type automatically.

The General Diagram.

In the general diagram (Fig. 1) shown, there is the apparatus at the transmitting station connected by a single main line 9 with the apparatus at the receiving station. I have placed a double marginal line around the apparatus at the transmitting station to distinguish it. The vibrating reed 1 is in a local cir-

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cuit with an electromagnetic motor 2. The reed makes and breaks its own circuit, and is substantially like the well known LaCour

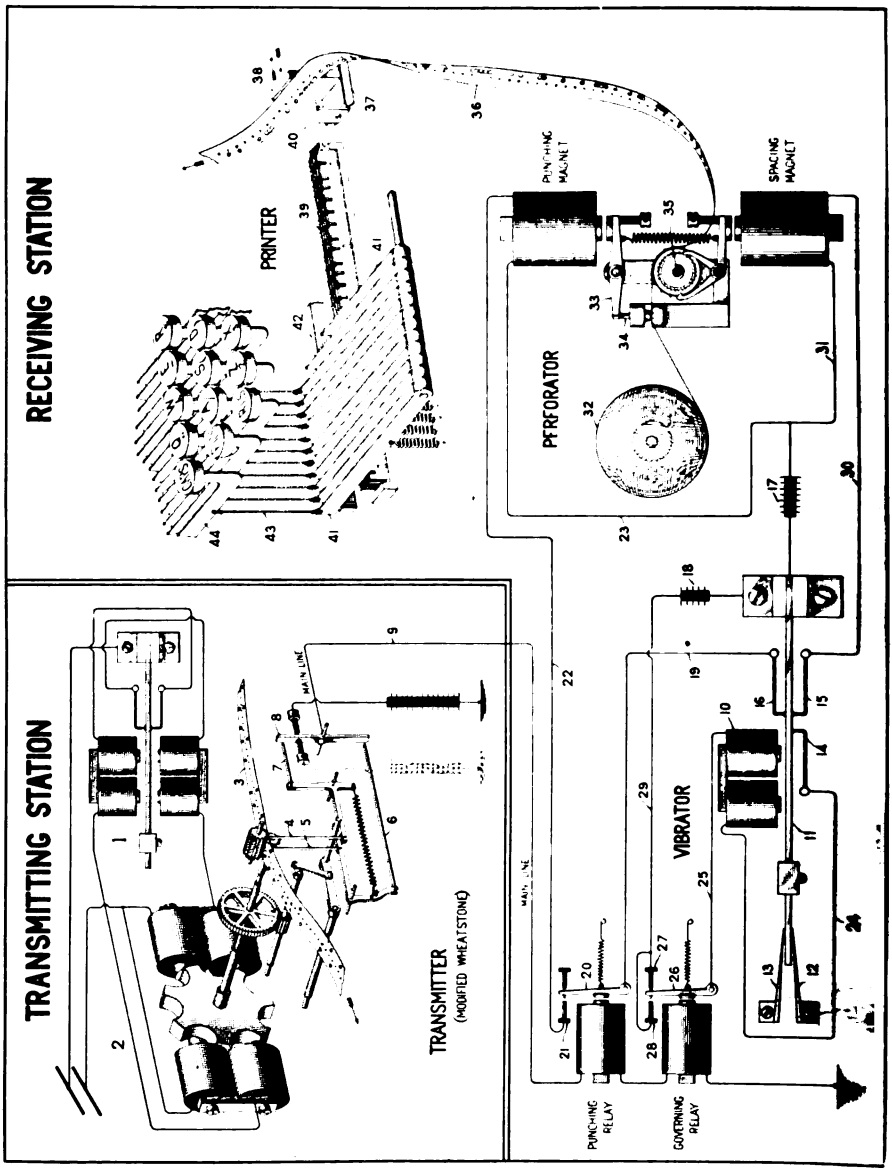

FIG. 1.

phonic wheel device. The "prickers" 4 and 5, familiar features in the Wheatstone transmitter are located as usual in line with the advancing lines of perforations in the transmitting tape 3;

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6 and 7 are reciprocating rods engaging respectively with opposite terminals of the centrally pivoted pole changing switch arm 8. The parts shown are all essential parts of the well known Wheatstone transmitter, which is here used practically without alteration, except that the prickers 4 and 5 are arranged to move or reciprocate together instead of alternately, thereby enabling any described multiple of a single impulse to be transmitted. The ordinary arrangement of the Wheatstone transmitter can only transmit unit signals or odd number multiples thereof; it is practically an alternating current generator. The Wheatstone signals have to be built up by omitting a positive or negative impulse, hence an ordinary Wheatstone transmitter can transmit a dot or a dash equal to three or five dots, but cannot transmit a dash equal to two or four dots. Mr. Murray, to avoid this difficulty, arranges the prickers to reciprocate together instead of alternately. There is thus obtainable, transmitted impulses or dashes equal to one, two, three, four, or five dots, with corresponding spaces.

In transmitting, the number of impulses thrown upon the main line is minimized by producing the impulses locally at the receiving station, and employing only sufficient main line impulses to determine the action of the perforator. At the receiving station there is, therefore, a main line relay to determine the action of the punching magnet, and a governing relay which operates to maintain unison between the main line impulses as they arrive and corresponding impulses in the local circuit. For the purpose of creating these local uniform impulses there is a vibrating reed, 11, operated by an electro-magnet, 10. The circuit of this magnet extends from the local battery 18 through the reed 11, contact point 14, wire 24, magnet 10, wire 25, armature 26 of the governing relay, thence by way of the points 27 or 28, and wire 29, to the battery. The precise operation of the governing relay I will describe presently. The receiving perforator is composed of a punching magnet and a spacing magnet; the punching magnet operates a spring-retracted pivoted armature bar, 33, mechanically connected with the punch 34, reciprocating through a guide block and engaging the tape 32 upon the surface of a suitable die, over which the tape passes. The tape is fed along by a star wheel located on a motor-driven shaft, 35, and upon this shaft is an anchor escapement under control of the spacing magnet. The vibrating

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reed 11 alternately makes and breaks the local circuit of the spacing magnet; this circuit extends from battery 17 to the reed 11, contact spring 15, wire 30, through the magnet and wire 31 to the battery. The punching magnet is in a local circuit with a break point operated by the vibrating reed 11 and controlled by break points of the punching relay, so that while the reed is continually generating local circuit impulses, these impulses are effective to operate the punching magnet at such times only as the punching relay is closed upon its front contact. This local circuit passes from the battery 17 through reed 11 to contact point 16, thence by wire 19, armature bar 20, contact 21, wire 22, through the punching magnet, and wire 23 to the battery. It will thus be seen that the reed 11 is continually making and breaking two circuits alternately; first, that of the spacing magnet, which is a continuous operation; and second, that of the punching magnet, which is an intermittent operation, rendered so by the action of the punching relay. This punching relay and also the governing relay may be either neutral relays responsive to makes and breaks, or they may be polarized relays responsive to reversals of current. As the reed 11 vibrates, the electric impulses in the spacing magnet circuit permit a steady progressive movement of the tape 36. Upon the arrival of an impulse of current from the transmitting station, the contact points 20 and 21 of the punching relay are held closed for one, two, three, four or five times the time interval of one dot length, and while this relay circuit breaker is closed, the punch 34 operates to perforate the tape as many times successively as permitted by the time length or duration of the transmitted impulse upon the main line. Mr. Murray has thus avoided the necessity of transmitting over the main line all impulses necessary to produce spacing, and all but a fractional part of the impulses necessary to produce the perforations. It is of vital importance, however, to preserve unison between the arriving transmitted impulses in the main line and the local punching and spacing impulses at the receiving station. This is done in the following manner:

How Unison is Maintained.

The governing relay operates a circuit breaker, 26, moving between two fixed contacts, 27 and 28, electrically connected to the same circuit terminal, so that the moving contact in going

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from one to the other operates to open the circuit during its time of transit only. I have referred to this briefly as "armature transit time." This break in the local vibrator circuit takes place at the beginning and end of each main line signal, and as the main line signals arrive at a uniform rate and are of unit or multiple unit duration, the governing relay operates its break-point at uniform unit intervals or multiples of these intervals. In the same circuit in which this break-point operates, there is also the break-point 14 of the motor magnet 10, which works on the familiar buzzer principle. There are thus two break-points in the same circuit. If they open and close together, then full vibratory impulses flow through the motor magnet. If, on the other hand, the rate of vibration of the reed tends to accelerate, or the rate of the arriving current signals tends to lag, then the two breaks occur more or less alternately and consequently less current gets through—the impulses are clipped—and the rate of vibration of the reed is reduced. In practice, the receiving vibrator is set to go one or two per cent. faster than the rate of the arriving signals, and then the governing action of the two interfering break-points in the same circuit results in the establishment of a steady dynamic balance between the accelerating tendency of the reed and the retarding tendency of the arriving main line signals. By this arrangement the necessity for sending correcting impulses over the main line to secure synchronism is avoided, the correcting impulses being obtained locally with the co-operation of the main line signals themselves.

It is to be understood that movable weights are present upon each reed, that of the transmitting station and that of the receiving station, and by varying the position of the weight upon the reed, the rate of vibration and the rate of transmission may be changed. At the receiving station there is provided means whereby the rate of vibration of the reed may be varied in harmony with variations in current in its motor magnet circuit. Under normal conditions with a motor magnet and circuit operated by break points carried by the reed, an increase of current, resulting in increased magnetic effort, will decrease the rate of vibration, and, conversely, a decrease of current resulting in decreased magnetic effort will accelerate the rate of vibration. This is believed to be due to eddy-currents generated by the magnetic field of force and the movement of the reed in such field. The action described while it has a damping effect, is of

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no practical use as a means of regulation for the work to which the reed is here put, because of its exceedingly limited range. It is necessary in maintaining unison to have a considerable range of variation in the speed of this reed, such variation in speed to be attained in response to variation in the length of current impulses of uniform strength.

Constrained Vibration of the Reed.

To secure this result there is placed at or near the free end and upon the opposite sides of the reed, resilient stops, shown at 12 and 13. These springs receive the reed on each side with a cushioning effect and impart an initial return movement. In explanation of this result it is to be recalled that the rate of vibration of a reed varies with its length, mass, and the distribution of such mass; increase of current in the motor magnet circuit increases the amplitude of vibration without varying the speed beyond the slight electro-magnetic damping effect already described. The energy imparted to the reed by the motor magnet is dissipated by the air resistance and molecular friction in the reed; an increase in the propelling energy brings a corresponding increase in the dissipation noted. Therefore, while the amplitude of vibration is widened, the speed is not increased. If fixed limiting stops be provided, to limit the amplitude of vibration, the energy of the reed cannot then be dissipated in the manner first described to the same extent, and there results an increase in the rate of vibration, while a portion of the energy imparted to the reed is dissipated in heat generated at the point of impact. To avoid this loss and further increase the rate of vibration, the energy which would otherwise be lost at a rigid contact is stored in the resilient devices, 12 and 13, already referred to, to cushion the impact of the reed, and impart an initial return movement. By this expedient, the movement of the reed is rendered smooth and uniform; it is freed from the interference due to the impact with a rigid stop, which acts to jar and disturb the normal rate of vibration, and its rate may be varied by varying the current impulses.

In further explanation of this device we may recall the fact that, within the limits of elasticity, a helical spring varies in length in arithmetical ratio with the force extending it; that is to say, if a helical spring extends one inch with a weight of one pound, it will extend two inches with the weight of two pounds,

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and so on. Within restricted limits the same rule holds good with simple flat springs of uniform thickness, like those commonly employed for electrical contact purposes. It has been found by experiment that springs of this kind, whether arranged for tension or for compression, do not vary the rate of vibration of the motor-driven reed to any appreciable extent in response to variations of current in the motor magnet circuit; but if resilient stops are constructed and arranged, like 12 and 13, to rapidly compound their resistance to the impact of the reed, they are practically operative for the purpose of varying the rate of vibration in response to variation in current.

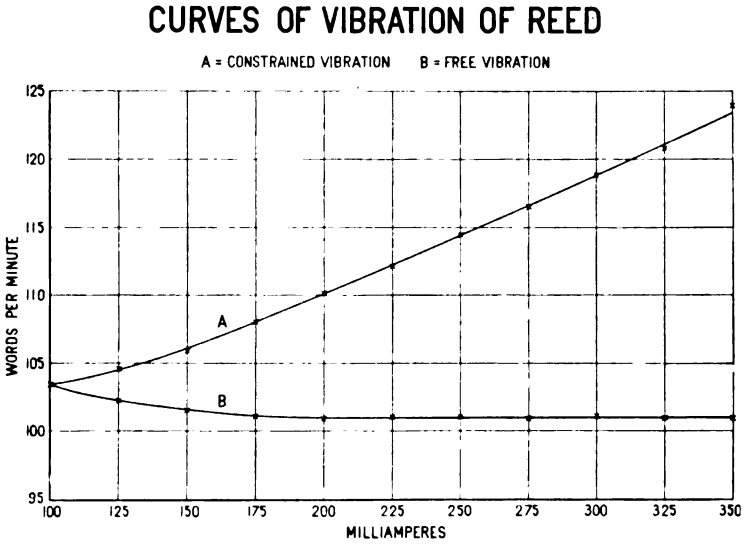

Fig. 2.

Curves of Vibration of Reed.

I have here a diagram [Fig. 2] showing the action of a reed when free to vibrate without limiting stops, as compared with the action of the same reed operating under the constraint imparted by the tapering springs, called resilient limiting stops. The figures were obtained by varying the amount of current flowing through the reed magnet coils and then measuring the amount of tape fed through the perforator under control of the reed. The tape is fed forward one step for each vibration of the reed, and its extent therefore gives an exact record of the rate of vibration per minute. The receiving vibrator and other

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instruments were set to transmit and record at the rate of 112 words per minute, and the current in the reed magnet was then varied with the following result:

Current in Milliamperes.	Tape fed per minute. ft.	in.
350	24	0
325	23	4⅔
300	23	0
275	22	6¾
250	22	1¾
225	21	8½
200	21	4
175	20	11
150	20	6
125	20	3
100	20	⅓

The action of the resilient limiting stops began at 100 milliamperes. The vibration with this amount of current was very slight. About 230 milliamperes were used for the 112 word rate.

The following table shows the effect of removing the resilient limiting stops, all other conditions being as before.

Current in Milliamperes.	Tape fed per minute. ft.	in.
350	19	6½
325	19	6½
300	19	7
275	19	6½
250	19	6¾
225	19	6½
200	19	6
175	19	7
150	19	8
125	19	9½
100	20	⅓

The reed did not vibrate reliably under 100 milliamperes, and even with that current it was feeble. The vibration did not become fairly strong until 125 milliamperes was reached. The figures and the curves indicate that the speed increases with decrease of current below 150 milliamperes. This was possibly due to the electro-magnetic damping effect of the iron armature vibrating in the magnetic field. Actual trial has shown that this effect is too feeble and unstable to be used for governing the rate of the reed by possible variation in the current. A more posi-

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tive and reliable result was required, and it was supplied by the resilient limiting stops. It will also be seen by the diagram that above 150 milliamperes the rate of vibration of the reed is uniform irrespective of the amount of current when the reed is not constrained by the resilient limiting stops. This is indicated in the straight horizontal portion of the curve B. Curve A shows the effect of the resilient limiting stops in causing an almost uniform acceleration of the speed of the reed in accordance with the increase of current. With respect to the curve A the variation in words per minute between extreme points is from 103 words with 100 milliamperes to 123 words with 350 milliamperes, and with respect to the curve B the variation in words per minute is from 103 words at 100 milliamperes to 101 words at 350 milliamperes, a perceptible decrease in the word rate, with an increase of 3½ times in the strength of current.

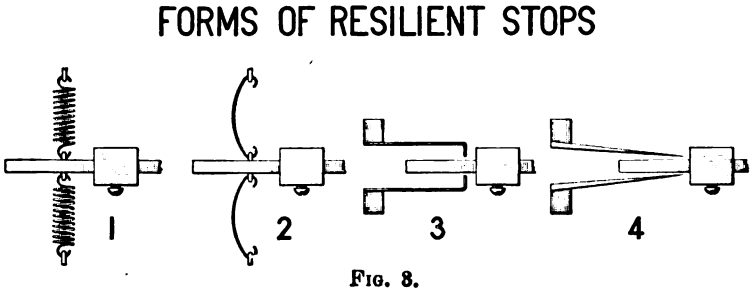

FIG. 3.

The forms of limiting stops experimented with and heretofore referred to are shown upon the diagram "Forms of resilient stops" [Fig. 3]. Nos. 1 and 3 are practially ineffective for the purpose intended; No. 2 is susceptible of some beneficial use, while No. 4 is a practically successful arrangement, and the one to be preferred.

THE UNISON DIAGRAM.

I have here a "unison diagram" [Fig. 4] to illustrate the relative position of the current impulses in securing unison. There is shown a section of receiving-tape in which appears the word "Paris," the division between the letters being marked with a dotted line. Below the line of the tape is shown the corresponding conditions of current in the local and main line circuits; when in unison, and again when out of unison. In line 1 there is shown the current impulses in the punching magnet

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circuit effective to produce the perforations shown on the section of tape; line 2 shows the current impulses in the local spacing current; at line 3 is shown the main line impulses due to the operation of the automatic transmitter effective to produce the perforation in the tape represented; at 4 is shown the operation of the armature of the governing relay, the unshaded divisions representing the "armature transit time," and the relative position of the armature transit with respect to the impulses in the main and local circuits; at line 5 is shown the impulses in the motor magnet circuit which operate to drive the reed; these impulses are shown as in unison with the main line and local circuit impulses. In line 6 is shown the same motor magnet circuit impulses out of step, or out of unison. The continuous operation

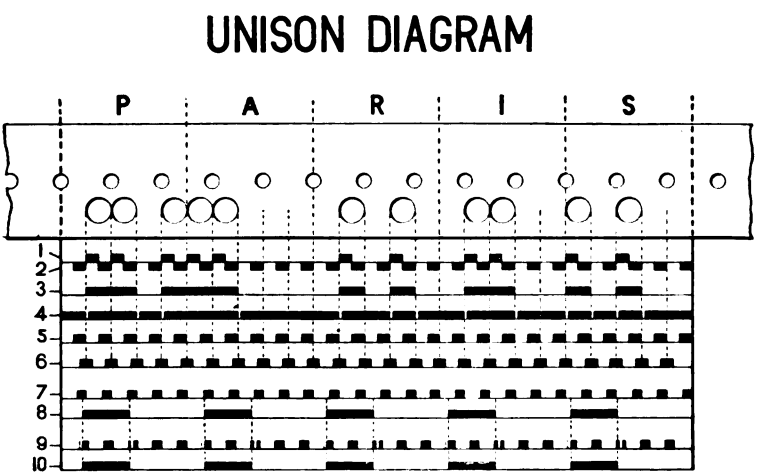

FIG. 4.

of the unison device is best illustrated in the actual record taken upon a chemically prepared paper tape with a pair of iron pens, one in the local circuit and one in the main circuit; the pens were arranged side by side; line 7 shows the record of impulses in the motor magnet circuit; line 8 shows the main line impulses, the action of the armature of the governing relay having been suppressed. In lines 9 and 10 the same means are employed to render graphic the impulses in the two circuits, and the operation of the transit of the armature bar 26 of the governing relay is also apparent in clipping the local circuit impulses, and thus curbing their motive power effect on the reed. There

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is thus established a continuous "dynamic balance" between the tendency of the reed to accelerate its speed and the tendency of the main line signals to retard its speed. The shape of the punch for perforating the receiving tape is quite important. A large number of forms were tried. The diagram "Forms of Punch" [Fig. 5], shows some of the leading shapes. No. 5 is much the best.

Telegraphic Alphabets.

In considering the merits of this arrangement of apparatus and in accounting for the want of commercial success of so many other arrangements, it may be said that printing telegraphs have not been generally employed for the following reasons, among others:

1. Delicacy and complexity.
2. Slowness of operation.
3. Limitation in the capacity of the operator.
4. The use of a tape for the received record.

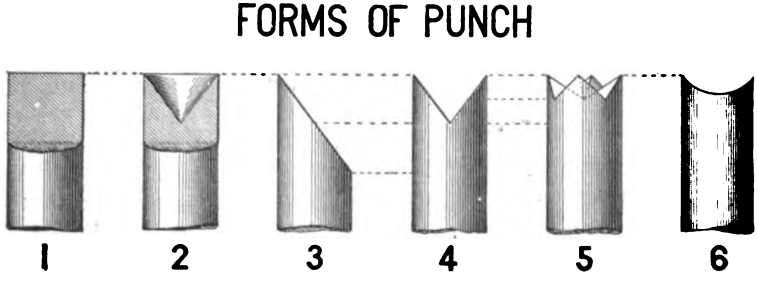

Fig. 5.

Recently some arrangements of apparatus have been devised which overcome these difficulties by two radically different methods; *i. e.*, automatic transmission and multiple transmission. The first uses the Wheatstone transmitter and perforated tape; the second employs direct manual transmission distributing the time for using the line between a number of operators. The slowness of operation has been due not only to the limitations of the operator, but also to the character and succession of the line impulses employed. In long distance working and with the growing use of underground and ærial cables, this is of extreme importance. The reliable material for high speed signaling over long distances in printing telegraphy consists prac-

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tically of five or six variations in the time interval; two variations in direction, and one variation in strength, *i. e.*, makes and breaks. Two very desirable conditions are that letters shall be of uniform length, and that either makes and breaks or reversals shall be used, but not combinations of the two. The Morse alphabet is ideal except for the great variation in the length of the characters.

The importance of an alphabet having letters of equal length has been generally acknowledged, and many designers have adopted the only practical arrangement, namely, thirty-two possible combinations of five positive and five negative elements taken five at a time. Such an alphabet was first suggested by Gauss and Weber of Göttingen in 1833. It was revived in 1874, when Baudot and others employed it for their multiplex printing telegraph systems. Baudot's arrangement, which may be taken as typical of this class of equal letter alphabets, is shown in the diagram called "Table of Alphabets" [Fig. 6]. It has the disadvantage of using makes and breaks as well as reversals, necessitated by the use of equal units of current to form the various combinations for the letters.

The Murray Alphabet.

Murray by using multiple units of current and space (that is by using several different time intervals instead of one only) avoids this disadvantage and has not found it necessary to use reversals, five different time intervals combined with makes and breaks giving all the combinations required. He has preserved the ideal simplicity of the Morse alphabet with the added advantage of securing letters of the same length. The Murray alphabet appears in the table; it will be seen that the uniform time for each letter is divided into five equal units or subdivisions, one or more of these five subdivisions being a current impulse, so that we get current impulses or spaces of one, two, three, four or five units duration. Thirty-two possible combinations are obtained in this manner, and by using two of these letter signals as prefixes to the others, capitals, figures, and lower case letters, about eighty-seven characters, may be transmitted. Makes and breaks or reversals may be used, therefore, adapting the system for use in quadruplex transmission; a use not practicable with an alphabet employing both makes and breaks and reversals. The alphabet is however only available for machine telegraphy,

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as it is practically impossible to observe five different time intervals with sufficient accuracy in manual transmission. No space is required between letters in the Murray alphabet, whereas in the Morse a three unit space follows each letter. This is shown in the "Table of Alphabets." It will be seen upon examination that the maximum number of impulses required is

TABLE OF ALPHABETS

	LETTERS	FREQUENCY	"MURRAY" SIGNALS	"MURRAY" TAPE	"BAUDOT" ALPHABET	"INTERNATIONAL" MORSE	"AMERICAN" MORSE
1	e	14,000		O····			
2	t	10,000		····O			
3	a	9,000		OO···			
4	i	9,000		·OO··			
5	n	8,000		··OO·			
6	o	8,000		···OO			
7	s	8,000		O·O··			
8	r	7,000		·O·O·			
9	h	6,000		··O·O			
10	d	5,000		O··O·			
11	l	5,000		·O··O			
12	u	4,500		OOO··			
13	c	4,000		·OOO·			
14	m	3,000		··OOO			
15	f	3,000		O·OO·			
16	w	2,500		OO··O			
17	y	2,500		O·O·O			
18	p	2,400		·OO·O			
19	b	2,000		O··OO			
20	g	2,000		·O·OO			
21	v	1,500		·OOOO			
22	k	800		OOOO·			
23	q	600		OOO·O			
24	j	500		OO·OO			
25	x	500		O·OOO			
26	z	300		OOOOO			
27	,	4,500		O···O	1		
28	.	3,000		OO·O·	2		
29	Space Key			··O··		BAUDOT 1 = É 2 = "ERROR" 3 = NOT USED	
30	Capital Key			·O···	3		
31	Figure Key			···O·			
32	Release Key			·····			

FIG. 6.

three for the letter y, and the average number reckoned according to the frequency of the letters is 1.25 impulses as against 2.59 for International Morse. As compared with this 1.25 impulses per letter, a system employing the Baudot alphabet has to transmit not less than five, and this does not take into account

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the necessary correcting impulses to secure or maintain synchronism. Murray has the shortest alphabet possible to be constructed from reliable signaling material and by combining it with machine transmission the entire time of the line is used in the most advantageous manner possible.

Comparison of Alphabets.

Referring to Fig. 7, "Comparison of Alphabets," it will be seen that the Murray word is shorter than the Morse in the ratio of 30 to 51, or 41.18 per cent. This theoretical diagram is borne out by a comparison made with an actual word such as PARIS. This comparison is made on lines 13 and 14. It will be observed that in this case the Murray alphabet is shorter than the Morse

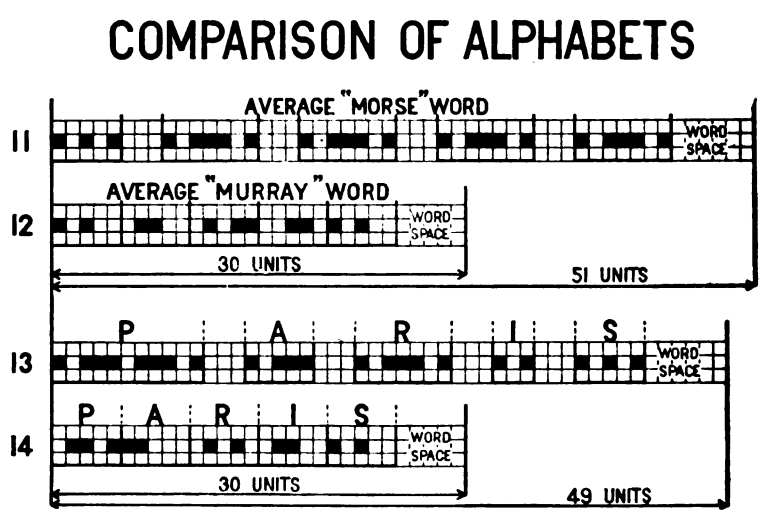

Fig. 7.

in the ratio of 30 to 49, or 38.78 per cent. Practically, the two alphabets are in the ratio of 3 to 5. Hence using the same number and length of current impulses in each case, a speed of 100 words a minute with the Murray alphabet would not be more than about 60 words a minute in Morse. The saving in the Murray alphabet lies chiefly in the fact that there is no space between the letters. Indeed, signals in adjoining letters not unfrequently coalesce, as will be seen in the case of the letters P and A in the word PARIS, where one current impulse is actually shared by the two letters, and five letters are transmitted by seven im-

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pulses, whereas in the Morse representation of the same word no less than 14 impulses are required. Many combinations of letters like te, ta, ma, me, ou, are sent by one impulse, and the German name Latzke, consisting of six letters, requires only four current impulses for its transmission. This, however, is exceptional, the average being 1.25 impulses per letter. The Hughes printing telegraph employs only one impulse per letter, but it is extremely wasteful of the space between signals, so much so that, on the average, not more than three impulses per second are transmitted over a line which will easily convey thirty per second. The Murray alphabet, on the other hand, economizes spaces as well as signals to the utmost extent.

Tests of the System.

From time to time, as the system developed, careful tests were made of its capacity, both on loops of varying lengths and on circuits between cities. The speeds mentioned below were calculated on the basis of five letters to the word and a word-space equal to one letter. That is to say, the receiving tape fed through the perforator in one minute was measured to find the number of letters it contained, and this number was divided by six. In April and May, 1900, a series of tests were made between New York and Chicago. Working direct from Chicago to New York via Meadville without a repeater, a distance of 1050 miles by the route of the wire, the best speed attained was 77 words a minute. Working with a repeater at Meadville, much better results were achieved, 102 words a minute being easily attained. The wire used was copper, 208 lbs. and 4.5 ohms per mile. Duplex working was readily secured. Attempts were made to reach a speed of 114 words a minute. These were only partially successful, but the results gave promise of a speed of at least 120 words a minute in the future.

The most exhaustive tests of the system were made, from the 17th October to the 3d November, 1900, between Boston and New York. Two hundred ordinary commercial messages were taken without selection from the files in the operating room of the Postal Telegraph Company in New York. They consisted of 160 business telegrams (including 18 in cipher) and 40 domestic and social. They averaged 10.8 words in the paid portion of each message. Following the usual practice of counting single figures as words, they averaged about the usual rate of 30 words

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per message; but counting figures as single letters, and counting all letters by measuring the transmitting tape and dividing by six, the average was about 26 words per message. These 200 messages were perforated in Wheatstone tape. A column press despatch from the *New York Herald*, containing 5988 letters and 1261 words, or an average of 4.75 letters per word, was also prepared in Wheatstone tape. This press despatch and the 200 commercial messages were transmitted from Boston to New York day after day at speeds varying from 60 to 96 words per minute. It was found that the apparatus worked with great accuracy, the whole 200 messages frequently coming through without error. At other times occasional errors occurred, owing to swinging wires and other familiar line troubles common to all telegraph systems. In addition to the 200 messages prepared beforehand in New York, a number of ordinary messages were perforated in Boston and transmitted to New York without difficulty, and almost without experience on the part of the Boston operators.

In regard to the number of messages transmitted per hour, in tests made when the apparatus was running at 61 words per minute, the 200 messages came through to New York in one hour 23 minutes. This is a speed of about 144 messages per hour, or more than three times the average rate of transmission by the Morse key, 40 messages per hour being regarded as a fair day's work for an average American operator. At the 96-word rate the messages came through at about 230 per hour. At the same rate the press despatch, with the last part repeated, making in all 1720 words, came through without an error in 16 minutes 42 seconds, or at the actual rate of about 103 words per minute, the words averaging only 4.75 letters each. A speed of 110 words per minute (115 actual words per minute) was tried, but at this rate not more than 200 or 300 consecutive words came through free from error. The inventor believes, however, that with increased skill and improved instruments, his system will ultimately reach a reliable speed of 120 words a minute. Working on a loop from New York to Albany and back, up one side of the Hudson River and down the other, speeds of 114 and even 118 standard words per minute have been successfully obtained. The length of the Postal Telegraph Company's lines from New York to Boston is about 290 miles, and the lines include from 20 to 30 miles of cable. Over this comparatively

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short line the system did not require any readjustment for weather, which varied during the tests from clear and cold to dense fog and rain all the way between the two cities. Duplex working was perfect.

It will be seen from the foregoing tests that this system, working at the 60-word rate, has a capacity of 140 messages per hour. Cutting this down to 120 messages per hour to allow for corrections and delays, and working duplex, there is an output of 240 messages per hour, or 50 per cent. more than the Morse quadruplex can achieve. Working at the 96-word rate, the system has the capacity to transmit two and a half times as many telegrams as the quadruplex. No doubt these figures will be considerably reduced in commercial practice, but there is a wide margin for such reduction.

The tests have shown that, owing to the characteristic alphabet, distances of 1000 miles are not an obstacle, and the inventor is sanguine enough to believe that it will be possible, though not at present commercially practicable, to work between New York and San Francisco, a distance of 3000 miles, at a speed of at least 40 words a minute, or double the rate of manual transmission.

I may add that W. H. Baker, the Vice-President of the Postal Telegraph Cable Company, to whose foresight is due the benefits of securing Mr. Murray's improvements, thinks that the received tape may be employed to operate a Mergenthaler Linotype Machine, or other type setting machine. Others, including Mr. Murray, are of the same opinion, but so far no use has been made of this application of the invention, commercially.

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NOTE.

The figures upon which the comparison of alphabets is based have been obtained by means of the following table, which shows the average number of signals per letter employed in the "International" Morse alphabet and in the "Murray" alphabet:—

1	2	3	4	5	6
Letters	Frequency	"Morse" Signals	Products (1)	"Murray" Signals	Products (2)
e	140	1	140	1	140
t	100	1	100	1	100
a	90	2	180	1	90
i	90	2	180	1	90
n	80	2	160	1	80
o	80	3	240	1	80
s	80	3	240	2	160
r	70	3	210	2	140
h	60	4	240	2	120
d	50	3	150	2	100
l	50	4	200	2	100
u	45	3	135	1	45
c	40	4	160	1	40
m	30	2	60	1	30
f	30	4	120	2	60
w	25	3	75	2	50
y	25	4	100	3	75
p	24	4	96	2	48
b	20	4	80	2	40
g	20	3	60	2	40
v	15	4	60	1	15
k	8	3	24	1	8
q	6	4	24	2	12
j	5	4	20	2	10
x	5	4	20	2	10
z	5	4	20	1	5
	1193		3094		1688
		$\frac{3094}{1193} = 2.59$		$\frac{1688}{1193} = 1.41$	

This table is based on the average frequency of occurrence of letters of the alphabet as shown by a printer's "bill of type" as given in "Practical Printing," by Southward. This frequency is given in column 2. In column 3 is given the number of "International" Morse signals for each letter, and in column 4 is given the products obtained by multiplying columns 2 and 3 together. The sum of column 4 divided by the sum of column 2 gives the average number of signals per letter as 2.59. "American" Morse reckoned out in the same way gives an average of about 2.4, or about 8% less. But when the space allowance between signals, letters and words is reckoned in, this 8% advantage is reduced to somewhere about 5%. Column 5 and 6 give similar figures for the "Murray" alphabet, which proves to have an average of 1.41 signals per letter. This average is reduced in practice to about 1.25, owing to the fact that the current impulses in two adjoining letters frequently coalesce. Taking into consideration the frequency of letters, the International Morse alphabet contains on the

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average 5 dots to 3 dashes. Hence as the average Morse letter contains 2.59 signals, the average Morse word of 5 letters contains approximately 6 dots, 4 dashes, and 5 fractions. This fraction is .59 of an average dot-dash. As there are on the average 5 dots to 3 dashes, and as 1 dash is equal to 3 dots, if we divide 14 by 8 we get the average dot-dash, which is in this way found to be equal to 1.75 dots. .59 of this is almost exactly 1 dot. The 5 fractions are, therefore, 5 dots. Hence the average International Morse word of 5 letters consists approximately of 6 dots, 4 dashes, and 5 dots (for the letter fractions), and the necessary spaces, namely, 1 dot-space between each letter signal, 3 dot-spaces between each letter, and 6 dot-spaces at the end of the word. The average word in the Murray alphabet consists of five letters, each letter containing 5 dot-spaces filled with various combinations of signals. The word space is of the same length as the letters, namely 5 dot-spaces. Having these figures, it is possible to make diagrammatic representations of an average word in the International Morse and in the Murray alphabet. This is done in the foregoing diagram headed Comparison of Alphabets. Line 11 gives an average International word, and line 12 gives an average Murray word.

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Discussion.

The President:—This very interesting paper is now open for discussion. The improvements which may be expected in telegraphy in the new century will undoubtedly be in this direction, namely, increasing the speed, and at the same time receiving the messages in printed characters, either directly or by machine transcribing, as in this case. There are several ways in which this can be done, as stated in the paper, and it is a matter of considerable interest to observe which of these methods are going to be successful in practice.

There are a few things which, it seems to me, were not made quite clear in the paper, and which might be interesting to have Mr. Vansize describe to us more fully. One is the way in which the page printing is done from the perforated tape of the receiver. It would also be interesting to know whether the apparatus is already in commercial use, and if so, how long it has been in such use. There is another point that occurred to me while listening to the reading of the paper, and that is, whether at the receiving end, the perforated tape could be used for relaying a message, and also for duplicating; that is, for redistributing the received message by repeating it over a number of different lines from central stations.

Mr. Geo. T. Hanchett:—I should like to ask, too, what means are used to manipulate the carriage of the typewriter, that is, to shift it when a line is completed, and to move the sheet up one notch? I presume it is done by the tape, but the mechanical motion afforded by the tape is not of sufficiently powerful character, it seems to me, to move the carriage or the paper.

Mr. Vansize:—In answer to the last question I will say that up to the present time it has been customary to let the supervising operator who is necessarily at hand, shift the paper, although I suppose it might be done by a characteristic perforation in the tape.

In reply to the inquiry of the President, I would say that the tape at the receiving station has not been adapted for repetition into another circuit. The received impulses differ in essential respects from the tape that is used for transmitting.

In regard to devices for actuating the typewriter itself, you will recall the fact that there is a separate instrumentality located below the typewriter in a frame. That instrumentality consists of a series of five combs, as we call them. Each comb is characteristically slotted. Lying across those combs at right angles are a number of thin metal bars in number corresponding to the number of independent keys on the typewriter. When a series of notches are in line below any one of those bars, one of those cross-bars which is connected to the typewriter lever will drop into it. The appropriate motive power is furnished by cams, and a description of the exact mechanical arrangement would be

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quite intricate. It is present there, in the machine which we exhibit. In order to get the combs aligned to cause the manipulation of any one letter, we employ a perforated tape. You can imagine the tape perforated, and you can imagine the tape having one-half inch lineal extent assigned to each character, and there may be one, two, three, four or five perforations, or one perforation may occupy any relative position between the ends of that half-inch space. The tape is fed along in front of a die-plate one-half inch at each step, and when so fed along one or more of the holes in the perforated section will register with one or more of five perforations in the die-plate. When a hole in the paper is in position and registers with one of the holes in the die-plate, the pointed end of one of the combs (before referred to) is in position, and free to pass through the perforation in the hole in the die-plate, or two or more combs may be in position to pass through registering holes in the tape and die. There is a cam which imparts to the die-plate an advance movement. As it advances the end of one or more of those combs passes through the holes in the paper, and also through the hole in the die-plate and the unperforated portion of the paper, backed up by the plate, pushes another group of the combs along with it. In that manner the notches are aligned under one or more of the bars, and when so aligned, one of the cross-bars will drop down. Up to the present time the motive power has been the human hand. There is no difficulty, however, in applying either electric or other motive power to the actuating device.

You ask the question, Mr. President, whether it was in commercial use. It has been practically adopted by the Postal Telegraph-Cable Company, and a set of instruments, having all the modern improvements which experimental work has determined upon as being desirable, is being installed, and it will then be put into use. It is not in use to-day.

THE PRESIDENT:—As I understand it, the operator at the receiving end turns a crank which operates the carriage and moves the paper along?

MR. VANSIZE:—Yes, sir.

THE PRESIDENT:—And the tape passes through, in the way shown here in this machine?

MR. VANSIZE:—Yes; in the ordinary way of hand-manipulation. Then the operator, when he gets to the end of a line, stops and mechanically returns the paper and spaces, and then turns the crank for another line.

DR. F. B. HERZOG:—I would like to inquire of Mr. Vansize what is the limit of speed at which this electrical device can be operated, and also what is the particular form of typewriter that has been adopted, and the limits of its speed in transcribing from the record?

MR. VANSIZE.—The limit of speed has not been determined in typewriting devices. Of course, there must be a limit beyond

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which the keys cannot vibrate. The limit of speed upon the transmitter depends somewhat upon the length of the line, of course. A number of perforators can supply a line with material for transmission; so that cannot be considered a limitation.

DR. HERZOG:—In the statements made concerning the record of the machine in the various tests, it was said that at a certain speed the signals were not received properly. Was that limit reached because the tape was perforated irregularly at that speed, or was it because the typewriting machine would not respond to the tape with sufficient speed? In other words, is the limitation due to the electrical operation of the receiving devices, or to the mechanical characteristics of the particular form of typewriter selected?

MR. VANSIZE:—The limit was due to the action of the perforator at the receiving station. Mr. Murray tells me that at the rate of 100 words a minute the punching magnet has to make 50 perforations per second.

MR. F. V. HENSHAW:—Do I understand that the limit, then, is the punching mechanism? Also, I would like to ask whether there has been any attempt made to devise a typewriter especially for this purpose, or whether you have simply utilized an existing machine? It would appear that if the limit of speed with which this system can be operated is due to the typewriting machine, that a machine could be devised in which the inertia of moving parts is very much less and much lighter, doing away with those heavy bars and keys, and thereby raising the speed perhaps.

MR. VANSIZE:—Mr. Murray has used the Bar Lock typewriter of the ordinary form that is on the market. He has not yet made any endeavor to simplify and lighten the parts of the typewriter, although he has contemplated doing so. The real limitation of speed is in the receiving perforator—the ability which it has to perforate the tape in response to the locally generated impulses; the limit of speed at which the magnet can charge and discharge and get the punch through the paper. It is a question of frequency.

MR. F. V. HENSHAW:—Have you ever tried a laminated magnet in order to increase the speed?

MR. VANSIZE:—The cores are slotted but not laminated.

DR. A. C. CREHORE:—I feel that the INSTITUTE should be congratulated upon having a paper of this character presented; I suppose partly because I am interested in the general subject. It seems to me there are many features of simplicity in this that ought to be commended. I refer to this particularly because very little is said in the paper about the transmitting arrangement. I would like to see a sample of the transmitting tape, and if possible, I would like to see the exact shape of the waves which are sent upon the line.

To do the work of cutting a perforated tape with only two

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electro magnets, is a neat if not an elegant achievement. It is evident, of course, that the limit of speed must be in that perforating magnet at the receiving end. Of course, if the limit was in the typewriter, another machine could be employed and the tape divided up between the two machines, or among three or four instruments.

I see there is a reed at both the transmitting and the receiving stations, which implies that there must be approximately a synchronism between the two stations. I would like to find out how much variation and how much latitude is permitted between the receiving and transmitting stations in order to have the apparatus work successfully. Would it be possible to have a rotating motor such as is a commercial motor at present? Could the speed easily be regulated within the limits which would be necessary to operate a receiving apparatus of this nature?

Then another point is the shape of the waves or the combination of the waves that can be drawn for two characteristic letters, such as A and B, or C, perhaps; showing how they would be if you used a polarized device and the non-polarized relays in the receiving end. Of course if you refer to the alphabet as given here, it is noticeable that you have got to come down to zero current some time in order to have the magnet become released. And after you have charged the line, I particularly have in mind long distance lines where the capacity effect is very great, and if you charge the line up to its full extent, and leave it charged for three or four semi-cycles, that charge must be gotten out sufficiently in order to release the magnet, and then another charge put in. The limit of speed on a long line, it seems to me, would be reached in that way; and it would seem, and probably has been found preferable, to use the reverse current for the longer line, in order to get the charge out.

Another point that occurred to me was, how much speed has been obtained, working on a local circuit, say, in a room. The speed limit of the apparatus can not exceed on a long line what it is on a short line of that character, and that will probably depend upon the rate which the perforating magnet can operate. I should be pleased to see the action of the perforator.

The use of letters of a uniform length it seems to me is a point of great simplicity in the system, although it is not novel, of course, to this special system. I would also like to inquire whether there is any great difficulty in reading the receiving tape, providing you know the alphabet? Of course if you did not have the words separated and attempted to begin at any point, it would be very difficult, because there is no space between the letters, and you would have to try five times before you would know what you were reading.

Also, I would like to know whether the speed can be easily changed. If the reeds are set to a certain pitch would it take

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you a long time to enable you to change to another pitch? Of course, in a Wheatstone apparatus it is very easy to do that, and I do not know that it is a very great point in the commercial use of the apparatus, but I know it is desirable to have a certain standard speed and keep at it. In fact, the English people would like to have a standard speed which they can use uniformly throughout the length and breadth of their island; and of course they will adopt such a speed as they can maintain upon all their lines.

Rather a general question would be in regard to usefulness of words coming out printed, like this, at the rate of 100 per minute, say, and words coming out at some higher rate, printed in Morse characters, which could be translated by an operator in the ordinary method, using a typewriter, and setting it up in print in the same way. If you could receive, say, 300 words by the dot and dash characters, such as in the Wheatstone, and only 100 in this printed way, and your lines were limited—which would you prefer? How would it be commercially determined?

MR. VANSIZE:—Answering the last question first, before it passes from my mind, I would say that that seems to be a commercial question as to whether you prefer to supply lines or to economize on the lines you have. It would seem with the facilities possessed by our principal telegraph companies, that we have lines enough, and it would be preferable to save the time of translation of the received Morse.

The attempt is made, and successfully made, to maintain unison between the *arriving current impulses* and the operation of the local impulse generator. It is not a question of unison between the transmitter and some instrument at the receiving station. It is the question of maintaining unison between the received currents, a sort of co-terminus unison. That is done by devices employing armature transit time.

In regard to the speed on a local circuit, of course we appreciate that as Dr. Crehore says, the limit of speed will undoubtedly be found, and is found in the electro-magnetic perforator used as the receiving instrument of the line. On a local circuit we have done 118 words in a very satisfactory manner, and that with the first instruments, possessing some defects, some slight features which might be changed to improve the general result. But 118 words is what we can safely calculate upon obtaining.

It is not practicable for us to read the received record from the tape. It could be done with instruments, but it cannot be done as a practical Morse operator would read the record from either a chemically prepared tape or an embossed tape.

DR. CREHORE:—Suppose you should displace one unit in your die, how would you then rectify it?

MR. VANSIZE:—We never have been confronted with that difficulty because the instrument does not permit of it. You

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step your tape forward one space each time. Of course, if it fails to feed, the thing is thrown out, and I suppose you would have to go back and start over again.

DR. CREHORE:—Suppose the word furnished a sufficient landmark to begin over again, you mean, then you would go back and begin over again; but I suppose there are errors very often in the perforation?

MR. VANSIZE:—Mr. Murray says that he has an apparatus for stepping it ahead one subdivision of a letter, in case the necessity arises for doing that.

THE PRESIDENT:—In this connection I would like to ask how you know where to begin when you feed your tape into the typewriter. You have to start with a certain fixed group of five holes; now, how do you know at which of that continuous row of holes the first group begins?

MR. VANSIZE:—You can go back to the beginning of the message. In telegraphic service the messages are all numbered, and you can start in on your tape anywhere, and you will soon find the beginning of the message, and then you can start in with a retransmission from that point.

THE PRESIDENT:—I do not think you quite understand the question that I asked; it is practically the same that Dr. Crehore asked. There is a continuous row of little guide holes in the tape, of which I understand groups of five correspond to each letter; now, in starting the typewriter, how do you know which of this regular line of holes begins the correct group? Of course the letters will be quite different, depending upon whether you begin the groups with the 1st, 6th, 11th, etc., or the 2d, 7th, 12th, or the 3d, 8th, 13th, and so on.

MR. VANSIZE:—That is true. In the case of the complication of the kind you indicate, which is entirely theoretical, we would go to the beginning of the message, which is indicated by a characteristic starting mark—take, for instance, four or five characters—we would go to that point and start again.

Referring back to Dr. Crehore's question, he asked if the speed could be easily changed. It can be easily and quickly changed. I should think five minutes would be sufficient to change its speed. You would have to change the weight on the reed at both ends if you wanted to change the speed.

The transmitting apparatus is the ordinary Wheatstone transmitter, which we have found it necessary to change to enable both of the so-called prickers to operate coincidently instead of alternately as is done in the Wheatstone system. That is because the Wheatstone cannot send a succession of the same impulses; it can only print one, three and five, while in Mr. Murray's system it is necessary to be able to transmit one, two, three, four or five, and by moving the "prickers," as the English denominate them, coincidently, that can be very easily attained.

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[COMMUNICATED.]

MR. HOLLON C. SPAULDING:—The writer is much interested in the subject of page-printing telegraph instruments to be treated in the paper by Mr. Vansize to be read at the meeting of the INSTITUTE on to-morrow evening, and regrets exceedingly that he is unable to be present to take part in the verbal discussion thereon. In view, however, of the various statements and references made in the paper, it may be of interest to the members of the INSTITUTE to know that the writer has for some time past been at work on a system of telegraphic communication which bids fair to fulfill the conditions involved in a theoretically perfect system more fully than the devices described by Mr. Vansize, or even indicated by his statements as to the necessities of the case. In the writer's opinion a system of telegraphic communication to be commercially successful should comprise:

FIRST.—A key-board of the ordinary typewriter form, and not requiring the services of a skilled operator.

SECOND.—Immediate and practically instantaneous registering of the desired character at the receiving end of the line.

THIRD.—The registration of an ordinary letter or type character instead of an arbitrary combination of elements which may be translated into one or more ordinary characters.

FOURTH.—The absence of synchronous devices for sending and receiving stations, and of electrical impulses varying in strength, both of which have been found impracticable in commercial use.

In other words, it is my belief that there is a demand for, and incidentally I have succeeded in producing a type printing electro-mechanism corresponding precisely to the ordinary typewriter, except that the key-board and printing mechanism may be separated by any desired distance and connected only by wires suitable for conveying electrical impulses.

Referring to the "forms of punch" shown on page 29, I would say that the writer has had occasion to use something of this kind in another invention, and while it is true that the form of punch indicated by No. 5 is preferable to the others, this could be still further improved by making it hollow, and beveling the teeth so that the end of the punch is practically a saw-section wrapped about an imaginary axis in cylindrical form. A slot should be provided near the cutting end of the tube through which is inserted a wire which will push out the paper disks as cut from the the paper, thus keeping the cylindrical cutting end clear at all times.

Boston, January 24th, 1901.

[COMMUNICATED.]

MR. WILLIAM MAVER, JR.:—Whether a thing is considered simple or otherwise often depends upon the point of view. Not long

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since, for instance, one of the leading electrical periodicals of London referred to a certain printing telegraph system that had been on exhibition at the Paris Fair, as of "awe inspiring complexity." Being somewhat familiar with the system referred to, I do not agree with this view of it, for, to my mind, it is comparatively simple in its mechanism and operation.

Doubtless one of the chief points of merit of the new telegraph system which has been brought to the attention of the INSTITUTE this evening by the kindness of Mr. Vansize, is its simplicity, for, if it be reliable and practicable in its operation, it must, I think be generally admitted by all who have given this subject any attention, that it is relatively quite simple in construction, and especially, as Mr. Vansize points out, as regards the alphabet employed.

Technically classified, Mr. Murray's system would probably be termed an "Automatic Page Printing Telegraph." The messages to be transmitted by it are prepared beforehand, analogously as in the case of the Wheatstone automatic system. That is, characters set to represent the letters of the message, are perforated on a strip of paper. This perforated paper is caused to send electrical pulsations over a main line, which pulsations operate apparatus at the receiving station, which, in turn, electro-mechanically perforate another strip of paper on a prearranged plan. This paper is caused to pass before a set of strips of metal that, in their operation, and, depending upon the position of the perforations in the paper, select a certain letter of a typewriter, in a manner which may perhaps be considered as somewhat similar to that in which the type of a linotype machine find their proper receptacles in the type distributing process.

The unison device employed by Mr. Murray is, I think, ingenious. A somewhat analogous principle for maintaining synchronism between the transmitter and receiver was employed in the Rogers printing telegraph, one of those numerous systems to which Mr. Vansize doubtless refers, which never passed very far beyond the experimental stage. In the Rogers system, as I remember it, a wheel at the receiving station was set to run at a higher rate of speed than the transmitter. A spot of light, or a spark, actuated by the arriving signals was thrown upon the side of the revolving wheel. This spot, so long as synchronism was to be maintained, was kept within a given space on the wheel (quite a little leeway being permissible) by manually applied friction on the wheel. Mr. Murray's method is, of course, more scientific.

It may be noted that Mr. Vansize has not shown, or indicated very fully, the manner in which the messages are received on a page by the Murray system. Provision must, obviously, be made for shifting the paper at the end of each line, etc., and it would, perhaps, be interesting to know whether such provision is made at the sending or receiving end of the line. The table

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of alphabets and comparisons of words which Mr. Vansize gives is of much value. Among other things, renewed attention is incidentally drawn, by this table, to the fact that the letter O, of the International Morse alphabet, employing three dashes, or 11 time units (O having a frequency of 8000), could change places to advantage with the letter K, which has a frequency of only 800, and in that alphabet employs but 2 dashes and 1 dot, or 9 time units.

The time units which Mr. Vansize has used for the dots, dashes and spaces are quite fair for machine telegraphy, such, for instance, as the Wheatstone automatic, which employs the Morse alphabet. But it is, I believe, the experience of most telegraphers that rapid Morse senders do not make the pronounced distinction between dots, dashes, and letter and word spaces. that theory requires and the machine system employs. The machine system makes the Morse dash equal to 3 dots; the space between letters equal to 3 dots, and the space between words equal to, say, 6 dots. A Morse operator sending rapidly makes the dash about equal to 2 dots, the letter space equal to 2 dots, and the word space equal to 3 dots. An examination of an embossed tape from a Morse register or recorder will, I believe, show this to be quite nearly the case.

It is perhaps worth noting that the different printing telegraph systems to which Mr. Vansize refers, the Baudot, the Buckingham and the Murray, do not greatly vary as to the message or word-carrying capacity they give to a wire. The Baudot, sending four messages, practically at once, over the wire, transmits a total of about one hundred and thirty-four words per minute. The Buckingham duplexed, about one hundred and sixty, and the Murray, duplexed, it is assumed about the same. A Morse quadruplex system, worked to its full capacity, gives about one hundred and sixty words per minute. The Baudot system, while not sending as many words per minute as the printing systems, does not employ a perforated tape for transmitting.

The further progress of the Murray system will doubtless be watched with much interest.

THE PRESIDENT:—The inventor of this very ingenious and simple system is with us to-night, and I am sure we should all be much pleased to hear from him.

MR. DONALD MURRAY:—I would prefer, gentlemen, to exhibit the mechanism rather than to describe it to you, because I think Mr. Vansize has very ably dealt with the subject, and I do not think I could add anything of interest to what he has said so well. I shall be very happy to show the machine to you after you have finished the discussion, and especially to call your attention to the arrangement by which the typewriter carriage is run back, as I believe one of your members inquired particularly about that feature.

There must be an operator to attend to the receiving of the

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message. You cannot have a purely automatic mechanism receiving and distributing the telegrams without supervision. There must be some one in attendance to read the telegrams as they are received, and therefore, while reading the telegrams, the attendant may just as well turn a handle and run the typewriter carriage back.

I have an arrangement for stopping the printer by means of a signal at the end of each line. This break-signal is put in the transmitting tape. When you are playing on the keyboard of the perforator that punches the transmitting tape, and wishing to make a break, you depress a key which inserts a break-signal in the transmitting tape. This break-signal is transmitted and recorded on the receiving tape, and by means of a clutch mechanism the break-signal stops the printer. The typewriter carriage is then run back by the attendant, and the act of running the carriage back starts the machine again. A man has to be there, anyhow, to attend to the receipt of the messages, and he can easily feed the paper into the typewriter and run the carriage back at the end of each line.

MR. GEO. T. HANCHETT:—I am not much of a telegrapher, but it seems to me that the commercial value of this machine will be subject to this condition. We have several systems which are giving satisfactory service; notably the Morse sounder and typewriter and operator. In this machine we have a more complicated typewriter and receiving instrument and also an operator. Now, there must be some gain for this additional complication.

I do not know how many words it is possible for an ordinary typewriter operator to take down in a minute, but I understand that it is possible to send by the Morse system as many words a minute as the ordinary typewriter operator can take down on the machine. I do not know, as I say, how fast a typewriter can be operated, but perhaps our stenographer could tell us.

THE PRESIDENT:—We would be obliged to the stenographer if he would give us some information on that point.

The stenographer stated that seventy-five words per minute was about the highest speed of an expert typewriter operator in writing from continuous dictation.

MR. HANCHETT:—Then, if that is so, it appears that here is a difference in speed between 75 words a minute and whatever this system is capable of——

MR. MURRAY:—If you would allow me to explain. The limit of speed is not in the ability of the receiving typewriter. The receiving typewriter can get up to a speed of ninety words a minute, though that is exceptional. I have had considerable experience with typewriter operators, and I think the average speed is not much more than fifty words a minute; indeed, it is a very good operator who does that. It is the transmitter who is at fault. Transmitting by the Morse key, the average speed

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is about 15 words a minute, working by the hour, and 30 words a minute is about the maximum.

MR. HANCHETT:—Then, if 15 words a minute is the average speed of the Morse operator, the gain between that and what is accomplished by this system, which is 100 words a minute, shows what the device accomplishes.

MR. MURRAY:—It is unlikely that the Morse key and sounder will ever be superseded for business requiring quick dispatch. The printing telegraph system described this evening and the others mentioned by Mr. Vansize are big high-power systems like express trains, and they are best suited for handling the mass of telegraphic business between large centers of population. I believe that in time they will each find special fields of usefulness in accordance with their particular capacities. The system described this evening is specially adapted for newspaper work, because the perforated receiving tape can be used to automatically operate a linotype or typesetting machine.

DR. CREHORE:—It is not quite clear to me yet by referring to Figure 4, where the unison diagram is given with the word "Paris," how it is made definite. For instance, take the black line of dots numbered 3 underneath; I understand that that line represents the current impulses coming over the main line. Is that so?

MR. VANSIZE:—Yes, that is right.

DR. CREHORE:—And the black represents the positive current. Then, does the white space immediately following, represent the negative current or no current?

MR. MURRAY:—Either.

DR. CREHORE:—Then would it be possible to divide, say, that first black space which covers two units in the letter "P" into two separate impulses and get the same effect if they were both in the same direction? I mean, could you divide it up in two and not necessarily have it continuous?

MR. VANSIZE:—Yes, sir.

DR. CREHORE:—Or, you could use two successive semi-signs in the same direction, could you?

MR. MURRAY:—I think that would be possible. The real trouble in using the alternating current is to get the time current intervals.

DR. CREHORE:—If the transmitting apparatus has to be as uniform in speed as the reed below vibrates, or very nearly so, how much variation would there be to that variation without interrupting the successful operation of the apparatus?

MR. MURRAY:—That is a question that I could not give you any very definite information about. It will run up as high as five per cent. above the transmitted currents and it will still govern; there is no trouble about that.

THE PRESIDENT:—We have with us to-night Mr. Jones, of the Postal Telegraph-Cable Company, and we should be pleased to hear from him on this subject.

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MR. FRANCIS W. JONES:—I did not come here prepared to enter into this discussion. I think the subject has been ably handled by Mr. Vansize. I think possibly the recording of messages upon the typewriter by the received perforated tape might have had a little more elucidation. The drift of the discussion is in the direction of the commercial possibilities of this system, as well as in the electrical and mechanical operation of the system itself. I have been in a position to watch the growth of this infant. The machine you see before you on the table, the combined typewriter with the actuating mechanism, was constructed in Sydney, Australia, by Mr. Murray, in a little workshop that I suppose could easily be placed on one corner of this platform, and I think the machine as it stands here, and as it has been operated, is a very great credit to him.

The system, as has been said, is a very simple one, and it is useless for me to criticize any of the theoretical defects in it because we have simply attached the wires to it between Chicago and New York, and between Boston and New York, and we have the messages here to show what it has done. So it is not for me to say it will not work, when it has worked, and when messages have come through the before-mentioned wires in very clear and nice shape.

It does not seem wise to let this discussion branch off into wild theories. The very best that Morse telegraphers can do, in a day's work, is about thirty words a minute. The simplest of all telegraph systems, outside of the telephone, if you wish to include it, is the Morse system, where a man sits with his hand on his key, his eyes steadily fixed upon the message, the words passing in through his eyes and out through his fingers over the wire into the ear of the receiving operator, and the latter printing it upon a portable printing press—a typewriter. There is no telegraph system that can transmit a message from the sender to his correspondent in so quick a time, except by telephone, as the Morse system operated in this way.

Now, the present plan is to perforate a tape by a keyboard, doing away with the skill necessary for a Morse operator to codify dots and dashes and so send over a wire. It is just simply a keyboard worked the same as the keyboard on a typewriter, and the resulting perforations in the tape are put through an ordinary Wheatstone transmitter, with the modifications that have been so clearly explained by Mr. Vansize, the prickers working in unison, or simultaneously up to the paper, and there it being determined which one shall go through the perforations. Then, at the receiving end, there is nothing but two relays in line for operating the punching and spacing local magnets, as has been explained. Now, the received tape is placed in the mechanically operated typewriter; Mr. Murray suggests that it is like a mechanical piano; you turn a crank, and it plays the tune, and that tune is the telegraphic message that has been punched at the other end of the line. As you turn this crank by hand or by motor, the

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typewriter keys are mechanically actuated, the type striking upon the platen, and so the message is gotten out in page form, the same as on any typewriter. The page moves forward, and when it comes to the end of the line the attendant pushes it back to its original position, and so it goes again, the attendant watching every line to see that there are no mistakes made. Thus every message is under constant surveillance, and is apt to go out to the correspondent in better shape than if a dumb machine actuated by the line currents were to grind it out automatically through a slot, because then no correction would be possible if a mistake were made in a line until after the correspondent got his telegram and sent a message back to the sending station, to say it was all pied, and to please repeat it; but this attendant at the receiving machine sees at once if anything is wrong, and immediately notifies the sending station—probably by the Morse key—(the system being quadruplexed) and the sending agent repeats, and so the message is gotten out accurately and without delay.

Another thing is, if you succeed in getting upon your line, say, 100 words perforated at the receiving end, it is not necessary to use only one machine; you can use two, or more. If one machine—as mechanical things do sometimes—gets a little out of order and won't work, you can turn to another machine which is all right, and go ahead; or, you can divide the tape up among two or more persons, if you want to print a lot at a time. That is distinctly a feature of Mr. Murray's system, that the currents coming over the line have not got to actuate a printer; the printing machine is a separate and independent machine, and stands by itself.

I am not prepared to enter into a discussion of the commercial features of this invention at all. It is to stand on its merits entirely. Those people who have their money invested, and who do the telegraph business of the country, will look the matter over carefully and determine whether it is to their interest to employ this machine or not, or to what extent they will employ it. It is certainly natural to suppose that in this new century there must come some improvement; that we cannot keep on putting up wires all the time in order to accommodate the Morse system, and the telegraph managers are watching as closely, and perhaps more closely than anybody else, to find what will serve their purposes best. They certainly do not want to put their money into wires, if, in the end, a little machine will do just as well. Some very clever systems have been devised—Mr. Delany's, and several others that I could name—but the trouble seems to be that while you can get a great deal over a wire, it takes a little time at the start, and a little time at the finish, which handicaps the business, and also that the expense of preparing the tapes and translating the tapes is so much more expensive than by the Morse system, and so much more complicated, and adds so much to the delay of the business, that neither the managers of the telegraph companies nor the public, whose

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business is to be transacted, will have anything to do with such systems. That seems to be about the size of the matter, as far as I can get at it. It is not because there is any prejudice at all, for there is no reason for prejudice. The Wheatstone system came to this country in 1880, and I believe there were seven circuits put up, and I think there are not five to-day. If it had been a good thing, and had satisfied the demands of the public, and also had satisfied the managers of the companies in respect to economy, it certainly would have been used more extensively. It does a large number of words per minute, and when duplexed, it is very efficient.

THE PRESIDENT:—I understand Mr. Jones to say that the limit of speed of the Morse system is thirty words a minute for each operator, and if that is quadruplexed, it makes 120 words a minute. So that the difference between a quadruplex Morse system, and a duplex system of this kind would be the difference between 120 and 200. Am I right?

MR. JONES:—Let me explain upon what I based my figures. Between New York and Boston, and some other cities, we have a system in the Postal Telegraph-Cable Company of paying an operator so much a day for his labor. He begins work at eight o'clock in the morning and quits at five-thirty in the evening, with a certain time for luncheon. We put four of those operators on a quadruplex in New York, and there are four in Boston. Those operators get a premium on each message beyond a certain number that they handle in a day. So that they get their regular salary and in addition to that so much per message over and above the number they are expected to do for that salary. Consequently they have quite an incentive to do their very best. Of course the business is ample to furnish all they can do. Now, it has been found that an operator in New York sending to an operator in Boston during that time will do at the rate of 60 to 65 messages per hour, and they average thirty words per message. I have taken thousands of messages out of our files, not only in one year but for years past, at intervals of one, two or three years, and counted them, and they vary between twenty-nine and a fraction and thirty words a message invariably. It is a very singular thing, but that will happen any time you count a bundle of messages indiscriminately. The very highest rate of Morse transmission is about thirty words a minute. Those are the very best operators—the very flower of the flock. Now, if you take the general run of operators, where there isn't piece work, and where they are not inclined to exert themselves to such an extent, where there is no incentive for it, I should think if you got fifteen words per minute on an average, you would be doing very well, indeed.

THE PRESIDENT:—I suggest that if there is no further discussion, the meeting might formally adjourn, and we can then gather around this machine and have Mr. Murray show it to us in operation, as he has kindly offered to do.

[Adjourned.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, February 28, 1901.

The 151st meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Hering at 8.30 P.M.

THE SECRETARY:—At the meeting of the Executive Committee this afternoon the following Associate Members were elected:

Name.	Address.	Endorsed by.
BAYLEY, GUY LYNFIELD	Assistant Manager Engineering Department, The American Trading Co., No. 28 Yokohama, Japan.	A. M. Hunt. Wynn Meredith. C. L. Cory.
BRUSH, FRED'K FARNSWORTH	Engineer in charge for Mr. F. J. Sprague. Societie Francaise Sprague, 6 Rue de Madrid, Paris, France.	Joseph Sachs. Wm. J. Hammer. Ralph W. Pope.
HOXIE, GEO. L.	Student in Electrical Engineering. Cornell University, 1192 Cascadilla Place, Ithaca, N. Y.	Fred'k Bedell. Harris J. Ryan. Edw. L. Nichols.
LEEDS, NORMAN	Electrical Engineer, Western Electric Company, 463 West St., New York, residence, Stamford, Conn.	H. F. Albright. F. A. Muschenheim. Geo. A. Hamilton.
SANVILLE, HENRY F.	Secretary and Electrical Engineer, Morris Electric Co., Splice and Terminal Co., 15 Cortlandt St., residence, 213 W. 105th St., New York.	F. B. Crocker. Max Osterberg. Max Loewenthal.
TOWNLEY, CALVERT	Manager, Boston Office Westinghouse Elec. & Mfg. Co., 53 State St., Boston, Mass.	Chas. F. Scott. L. B. Stillwell. Wm. Lisp'd Robb.

Total 6.

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The following Associate Members were transferred to full Membership.

Approved by Board of Examiners, October 26th, 1900.

CLARE F. BEAMES	Chief Engineer, Compania Mexicana de Gazy Luz Electrica, City of Mexico.
JAMES A. WOTTON,	Manager Wotton Electric & Mfg. Co., Atlanta, Ga.
FREDERICK W. HADLEY,	Electrical Engineer, care of Westinghouse, Church, Kerr & Co., New York.

Approved by Board of Examiners, October 12, 1900.

STEVENS, J. FRANKLIN	President Keystone Electric Instrument Co., 9th St., and Montgomery Ave., Philadelphia, Pa.
VARLEY, RICHARD JR.	President, the Varley Duplex Magnet Co., 138 7th Street, Jersey City.
LEYDEN, HARRY RUSSELL	Mgr., Hamilton Elec. Lt. & Cataract Pr. Co., Hamilton, Ont.

THE PRESIDENT:—The paper of the evening is on "Important European Electrical and Engineering Developments at the Close of the Nineteenth Century," by Mr. William J. Hammer.

Mr. Hammer read the paper.

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A paper presented at the 151st Meeting of the American Institute of Electrical Engineers, New York, February 28th, 1901. President Hering in the Chair.

IMPORTANT EUROPEAN ELECTRICAL AND ENGINEERING DEVELOPMENTS AT THE CLOSE OF THE NINETEENTH CENTURY.

BY WILLIAM J. HAMMER.

The author of this paper has found it impossible to do even scant justice to those subjects, which he has selected, without going somewhat fully into details in each case. He will not attempt to read it in full, but endeavor to present the salient points as the lantern slides are shown.

The Telephonograph.

The telephonograph, or, as it is sometimes called, the "telegraphone," the "microphonograph," and the "magnetophonograph," is the invention of a Danish electrical engineer, Mr. Waldemar Poulsen, of Copenhagen, Denmark. This beautiful and ingenious instrument was considered by all those who had the opportunity of seeing and testing it at the recent Paris Exposition to be the most interesting scientific novelty there exhibited. In principle it is so simple it seems remarkable, that with all our familiarity with electricity and magnetism, such an invention should not have been made long ago. The apparatus, which is indicated in Fig. 1, consists of a drum of brass about $11\frac{1}{2}''$ in length by $5\frac{1}{2}''$ in diameter. On this drum, which is revolved by means of an electric motor, is wound 225 turns of steel piano wire, of a diameter of about one mm. Supported above this wire, and in contact therewith, is a tiny magnet, such as are shown in Fig. 2, letters A and C which are almost natural size. This magnet is attached to a brass support, mounted

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on a shaft, so that as the drum or cylinder, carrying the steel wire revolves, the magnet is caused to move from right to left across the drum, being guided by a grooved finger, resting upon the steel wire on the drum, each turn in the steel wire passing consecutively before the poles of the tiny magnet. On reaching the end of the cylinder, an arm mounted on the left side of the frame strikes the tiny lever shown in the illustration, raising the magnet, and causing it to run rapidly back to the beginning again (the carrier being guided by the coarse threaded shaft, shown parallel to the supporting shaft) this operation taking but five seconds. The legs of this magnet are about $\frac{7}{16}''$ long, and

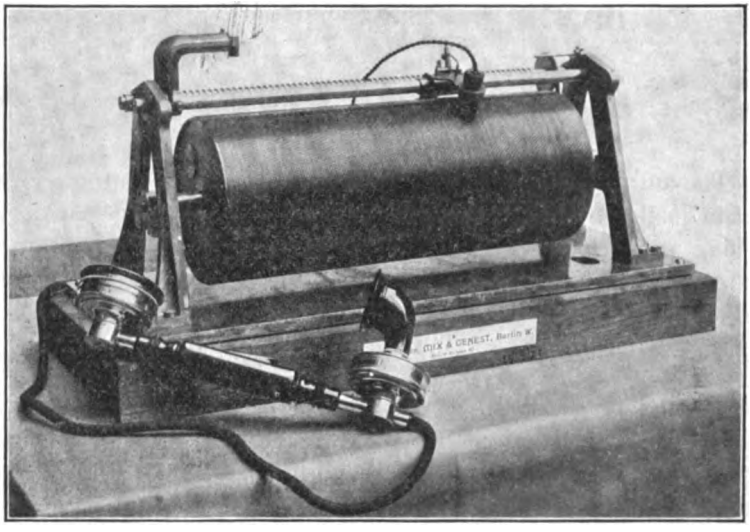

FIG. 1.—Poulsen's Steel Wire Telephonograph.

are wound with bobbins of wire of about the same size as those employed on an ordinary receiving telephone magnet. A cross-section of the magnet is shown in Fig. 2, letter C. It has been found that a horseshoe form of magnet, as shown in Fig. 2, letter B, will not respond rapidly enough, and it is preferable to employ two separate magnets electrically connected, as shown in Fig. 2, letter C. In the ribbon form of telephonograph, the horseshoe magnet shown in Fig. 2, letter D, may be used, but even here two magnets electrically connected are preferable. This recording electro-magnet, which has a resistance of 100 ohms, is connected in circuit with an ordinary carbon telephone transmitter, and a couple of cells of bat-

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tery, and preferably with an induction coil in the usual manner. When the transmitter is spoken into, it acts as a tap upon the battery, and causes currents of varying strength, and in proportion to the strength of the sound waves impinging upon the diaphragm, to pass through the wire wound on the electromagnet. Now as the steel wire wound on the drum passes in front of, and in contact with the poles of the magnet, its varying magnetic field magnetizes transversely the steel wire, and the "lines of force" are permanently recorded therein. After the steel spiral has been filled, which operation takes about 39 seconds at an ordinary speed of talking, and records 100 to 120 words, the tiny magnet is placed at the point where the record first started, and in place of the transmitting telephone with which it was connected, a Bell receiving telephone is attached. The cylinder or drum again revolves, and as the magnetized steel wire passes before the poles of the electromagnet, it forms a species of magneto-

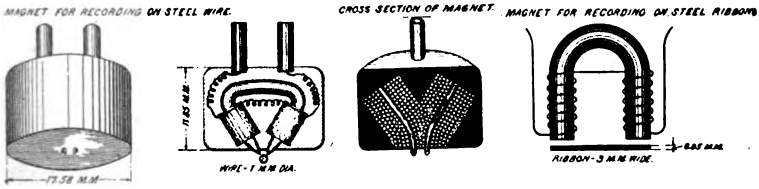

FIG. 2.—Telephonograph Magnets.

electric generator, giving out currents of electricity of a strength and direction corresponding to the magnetization of the steel wire, which correspondingly affect the Bell telephone, and reproduce the sounds and words originally spoken with absolute fidelity. In Edison's phonograph and its modifications, such as the graphophone, gramophone, etc., a stylus is always employed to indent the surface of wax, metal, or other yielding substance. The stylus resting upon such a surface, and being attached as it is to the vibrating diaphragm of the phonograph transmitter, is affected by the dampening effect of the needle or its inertia, and the higher harmonics are more or less destroyed, and there are also false sounds produced, due to the molecular disturbances in the needle and diaphragm itself. Although Mr. Edison has recently made remarkable improvements in the perfection of recording and reproducing by means of his phonograph over his earlier forms, there are difficulties such as I have referred to, which it

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has heretofore been impossible to overcome. In Poulsen's telephonograph, however, the tiny magnet not being in contact with the steel wire, the lines of force are silently stored up, and without being affected by external influences. The author has had considerable experience in working with various types of phonographs, and was accorded facilities to examine and operate the telephonograph, both at Paris and at Berlin, and still more recently here in New York. In Berlin, Messrs. Mix and Genest have for some time past been conducting a laboratory for experimental development of the telephonograph, and through

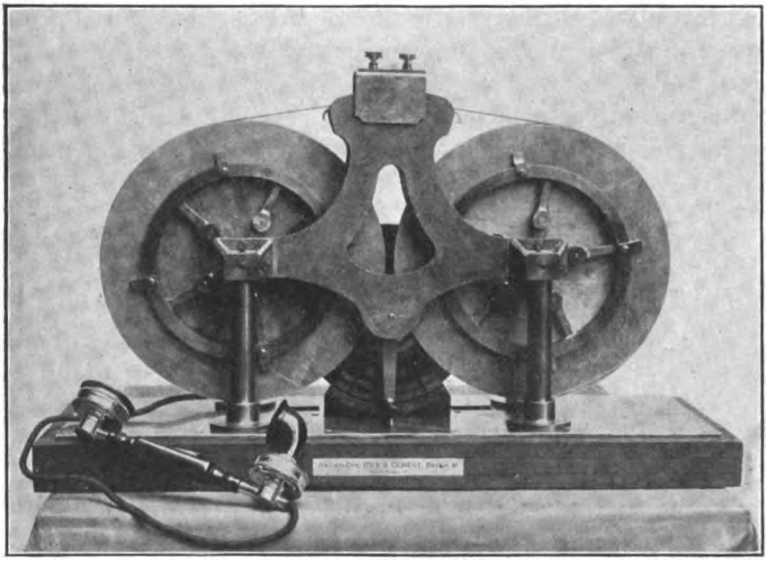

FIG. 3.—Poulson's Band Telephonograph.

their courtesy, and that of Director Zopke, I. was afforded the pleasure of visiting this laboratory, and saw some very interesting developments in this promising field. I found the instrument would record and reproduce the most delicate sounds, even breathing and very low whispering, and certain words, which those who have had experience in working with the phonograph know have always been very difficult to record and reproduce perfectly. All have been taken care of most perfectly by the telephonograph. If it is not desired to retain the record made upon the steel wire, the recording magnet is placed at the end of the drum, and connected with a couple of cells of

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battery, which supply a constant magnetizing current to the magnet, which entirely obliterates the records which had been stored up in the steel wire, as this wire is passed before the poles of the magnet. A permanent magnet may also be employed for this purpose.

Another type of instrument which Mr. Poulsen has designed, is shown in Fig. 3. This consists of two reels, carrying a band or ribbon of steel about $\frac{3}{16}''$ wide and about $\frac{1}{32}''$ thick. This steel ribbon which may be made of any length and which may be recorded upon for an hour or more at a time, is passed from one reel to the other—the reels being operated by a small electric motor. Above the steel band or ribbon is placed a tiny electromagnet of the form shown in Fig. 2, letter D, which is connected to a telephone transmitter and battery, in the same manner as in the instrument already described, and after a record has been made, is also connected to a Bell telephone, as a reproducing instrument. It is stated that these steel ribbons after receiving the magnetic record could be wound in many layers, similar to a spool or bobbin of ribbon without affecting the record, and that the record could be reproduced thousands of times. It is said that a record has been reproduced 2,200 times and has still been very perfect, and such a spool containing a record could be shipped across the country and placed on another machine, and would reproduce the sounds which originally caused the record, with absolute perfection, and even a rusty wire containing a record has been sandpapered and polished, without affecting appreciably, the record. In Fig. 5, letter D, is indicated: first, how the steel band is magnetized by the obliterating magnet, then by the varying field of the recording magnet, and finally, by the reversal in direction. The Poulsen telephonograph in its ordinary form does not speak louder than an ordinary Bell telephone. I would suggest the employment of Edison's "electro-motograph" or "chalk" telephone receiver, by means of which it could be made to speak very loud. (An audience of 5,000 has been able to hear perfectly this Edison's loud speaking telephone). Mr. Poulsen has suggested a number of other methods by which the sound could be augmented. It is claimed that by increasing the speed during reproduction, over that of the recording speed, that the telephone speaks much louder. This would, however, tend only to increase the pitch, and not improve the volume of the sound. Other methods suggested by Mr. Poulsen are indicated in Fig. 5, letters A and C. They

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consist in substance of methods for causing one transmitter to make a number of records on separate steel wires or bands which, on repeating, cause the various reproducing magnets to simultaneously affect the one telephonic receiver. It has also been proposed to utilize the telephonograph as a talking newspaper. In Fig. 4 is shown a method which it is proposed to employ. As the steel ribbon which, in this particular form is endless, and which is receiving the record, passes from one reel to the other, as indicated by the arrows, it passes consecutively before each of the receiving magnets, which are shown in horseshoe form, but which may also be single pole, and the subscribers, whose telephones are attached to these magnets, are thus constantly being

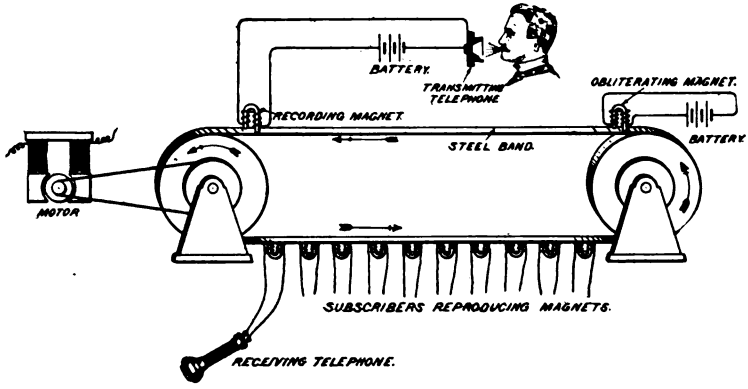

FIG. 4.—The Talking Newspaper.

supplied with the latest news of the day, stock quotations, etc. After the ribbon or band has passed before these magnets, the obliterating magnet wipes out all of the magnetic lines of force stored up in the steel band, and it then passes on to receive fresh impressions from the recording magnet and telephone. In this connection I wish to say that in Budapest, I recently found a talking newspaper system being run in connection with the supplying of music, and talking from the theatres by means of the "theatrophone." During the day the subscribers were constantly being informed of the latest news of importance. This service which supplied many thousands of subscribers was independent of the regular telephone service. I also remember equipping the Theatrophone Co. in Paris in 1889 with two Edison phonographs for a like purpose—this being the first attempt in this direction.

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Many suggestions have recently been made for employing the telephonograph in telegraphic and telephonic work, just as were made many years ago when Edison invented his phonograph. It remains to be seen how important the practical applications of this wonderful scientific instrument will become, but it is self-evi-

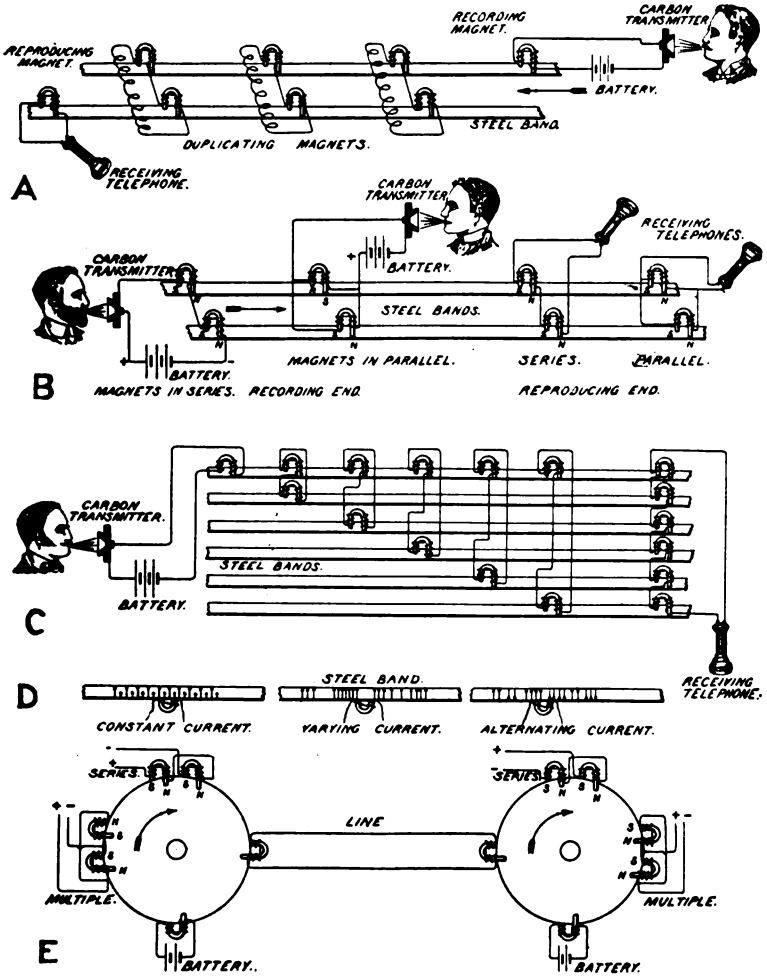

FIG. 5.—Proposed Methods for Increasing Volume of Sound and for Duplexing.

dent that any invention possessing such intrinsic merit, is certain sooner or later to meet with important commercial applications. The author in common with many others has used the phonograph in his office; dictating at his convenience his correspon-

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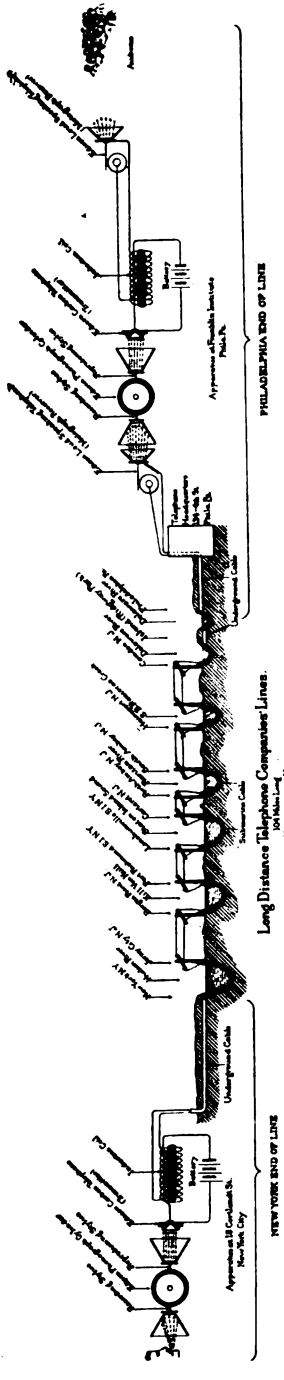

FIG. 6.—The author's Telephone Relay Experiments made on Feb. 4th, 1889.

dence upon the cylinders, from which it was later transcribed by the typewriter. He was recently shown and operated a form of Poulsen's telephonograph, which had three magnets attached to the recording magnet carrier, which enabled him to start, stop, and reverse the movement of the carrier, and also obliterate errors in the wire. In Fig. 5, letters B and E, are shown two methods proposed for duplexing. The two sets of magnets are shown connected, in the one case, in parallel; and in the other, in series. These magnets may all be connected in series, or all in multiple, but it is essential that they should be with the proper polar relation. It is claimed that these two sets of recording magnets send waves of a different character over the line, and at the receiving end of the circuit, each reproducing magnet will respond to its proper wave. I believe the form shown in Fig. 5, letter E, has never been demonstrated to be practicable, but the one employing the two ribbons shown in Fig. 5, letter B, has been operated successfully. Suggestions have been made for using the telephonograph as a telephonic relay, and I am informed that some experiments have been made recently in this direction, in Europe, and it may perhaps not be out of place in this connection, to call attention to the experiments made

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by the author in employing the phonograph as a telephonic relay, at the time of his lecture on "Edison and His Inventions," delivered before the Franklin Institute on Feb. 4th, 1889, which experiments were described in the *Electrical World* of Feb. 16th, 1889, and other papers, and subsequently more fully described in the *Electrical World and Engineer*, of June 3rd, 1899. The diagram shown in Fig. 6 illustrates very clearly the arrangement of the two phonographs, four telephones, two sets of induction coils and batteries and other apparatus, circuits, etc., and these experiments, constitute, I believe, the first practical form of telephonic relay, which has ever been constructed, and which operated with perfect success over 104 miles on the lines of the Long Distance Telephone Company, between New York and Philadelphia. (It is interesting to note that the sound passed through the air five times, through fifteen separate mediums, and changed its physical characteristics 48 times in transmission.)[1]

[The author here exhibited samples of the steel wire, steel ribbon and magnets employed in connection with the Poulsen Telephonograph.]

The Langen Mono-Rail Suspended Railway.

It is not possible at this time to go into the history of the development of suspended railways. It suffices to say that practically all of the designers and constructors of such systems have feared the oscillations of the suspended carriages, and have resorted to auxiliary carrying rails or guiding rails, the latter being designed to prevent lateral swaying, and take up side pressures. Various types of swinging railways have been termed "mono-rail," although it is probable that the Engen-Langen system, now being installed between Barmen, Elberfeld, and Vohwinkle, near Cologne in Germany, is the only line to which this term can strictly be applied. The original plan for this road contemplated a two-rail track, but the experts called in by the Barmen and Elberfeld municipalities to advise upon the Langen system, finally decided upon the single rail plan, it being decided that the mass of the carriage was so great, and its vibrations so slow, that it would be possible to get rid of unpleasant oscillations without its being necessary to use auxiliary rails. It was believed

1. See *Electrical World and Engineer* of June 3d, 1899.

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that guide rails sacrificed most of the advantages which suspended railway carriages presented. Considering certain disadvantages in surface roads, it is claimed that apart from the limits of speed, which points and switches impose, the two rails of surface tracks are themselves detrimental, as they cannot always be kept parallel, or at the same level. The carriages consequently must vibrate, and the permanent structure be affected more or less seriously. On curves in surface lines, the outer rail is raised, care being exercised not to overdo it, and the ratio in the level of the rails varies with the speed. High speed

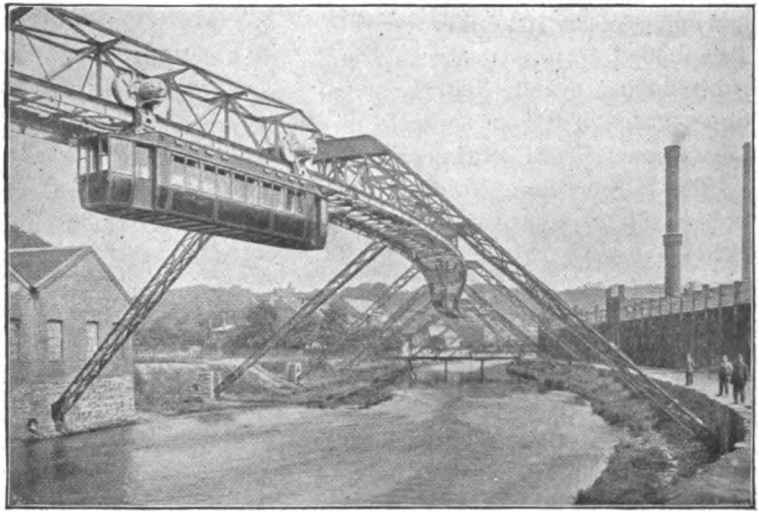

FIG. 7.—Suspended car passing over Wupper River.

is generally impossible on surface lines, and when elevated structures with double tracks are employed, they are of necessity objectionable from an æsthetic point of view, and they furthermore obscure the light. A mono-rail track will be lighter, and in every way less objectionable. Curves can be managed with but slight oscillations,—in fact, curves with a radii of 50, 25 and 10 metres have been passed over with speeds of 41, 30 and 16 miles, deflecting the carriages by 35, 36 and 27 degs., and still no motion was felt by the passengers. The carriages on the Elberfeld road do not diverge more than seven degrees. The sharpest curve of the track proper, has a radius of 295 feet; and

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only where some exceptional accident happens to the structure or foundations thereof, is there any danger of derailment. Prof. Dolezalek of Hannover, after inspecting the Elberfeld line, in March, 1900, stated that such a system might with great advantage be employed at the termini of railways in large towns, where an extra suspended line could be placed over the permanent track, thus utilizing the same area for two railway lines, increasing the carrying capacity of the road, without enlarging

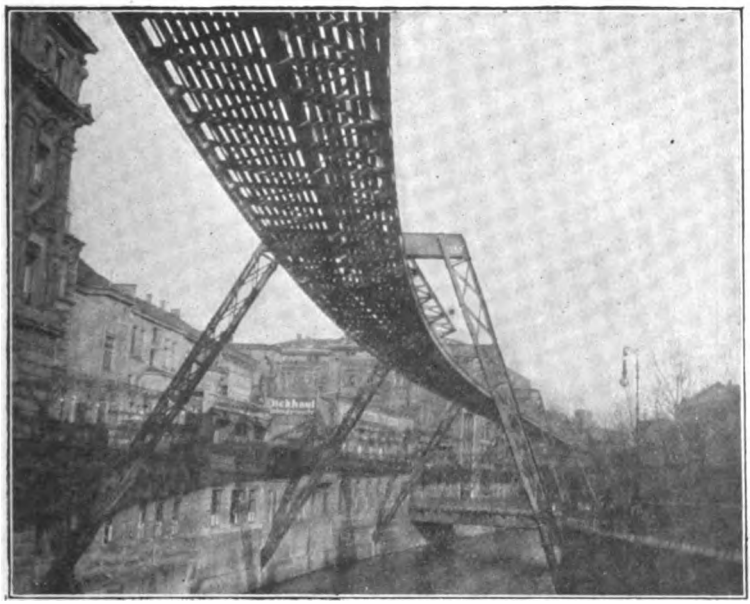

FIG. 8.—Structure above Wupper river and bridge.

the site, and by this means sending the long distance high speed traffic over the elevated structure, reserving the surface track with its complications, for the local traffic. The length of the Elberfeld line: when completed, will be eight and one quarter miles; 6.2 of which passes over the River Wupper, a tributary of the Rhine, which varies in width from 68 to 115 feet. Barmen, Elberfeld and Vohwinkle, which towns the railroad connects, are situated in the narrow Wupper Valley. No satisfactory route existed for a surface road, and it was deemed impracticable on account of the expense and engineering diffi-

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culties, to construct an ordinary type of elevated railroad. I was informed by the engineers of the Elektricitäts Aktiengesellschaft (formerly the Schuckert Company) who are constructing the road, and through whose courtesy I was given a special trip over a completed portion of the road at the time of my second visit, on Nov. 12th, 1900, that the total construction expense for the loop track at Elberfeld, amounted to $224,000. per mile, and the total cost of the road when completed would not be over $2,500,000. for the eight and one quarter miles. The accompanying illustrations

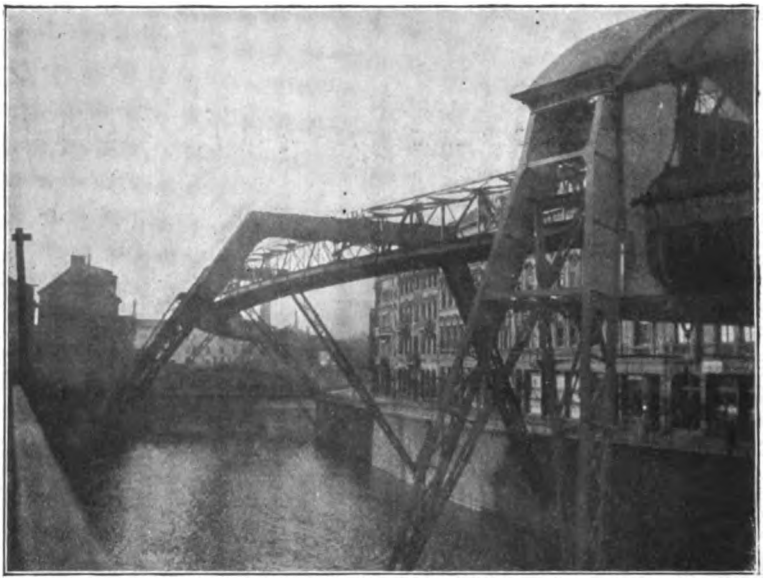

FIG. 9.—Supporting structure over Wupper river.

Figs. 7 to 12, and the lantern slides, give a general idea of the construction of the road, and in the main are from photographs taken by me at the time of my two recent visits. The cars are 37.5 ft. long by 6.5 feet wide, and accommodate 50 passengers each, with seats for 34, who enter and leave by two side doors, opening inwardly. A partition divides the car into smoking and non-smoking compartments. Sections of the opposite sides of the car open outwardly, and become a platform across which the passengers can pass to the cars of a train going in the opposite direction, in case of an accident happening, which disables a car. The doors lock automatically, and

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the motorman releases the catch. The end platform guard rails can also be lowered so that the passengers can pass into a train following the disabled one. Two telephone wires are attached to the structure, and by means of a bamboo pole, carrying metal clips, connection can be made from any car to the power house, and various stations on the line. Automatic ticket vending boxes are used along the line. The currents supplied to the up and down track are separate, and a large storage battery is installed

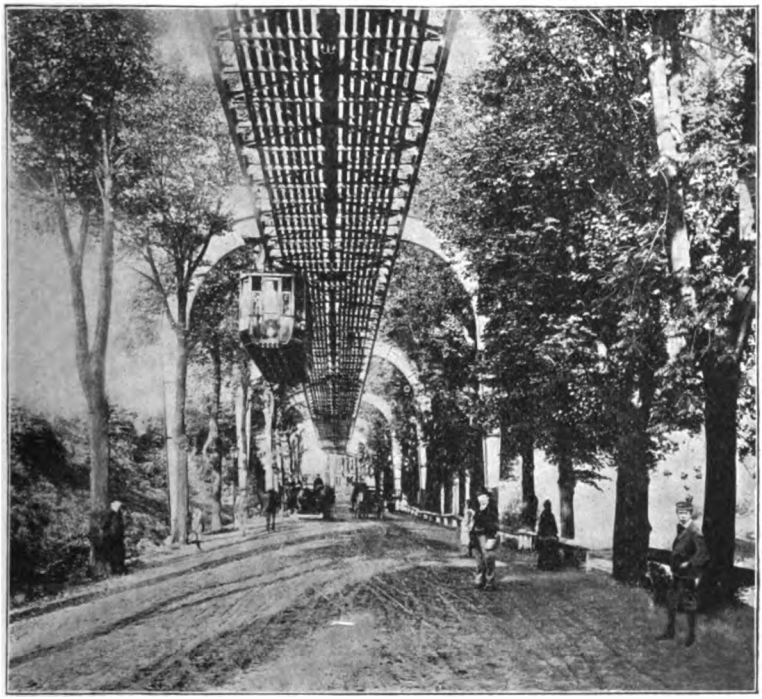

FIG. 10.—Railway passing over roadway.

at the central station. Each train consists of two carriages, but may be increased to four or more, all connected together by rods to secure rigidity. In the front compartment of the first carriage, is the controller for all the motors. As the trains always move in the same direction, it is not necessary to have a controller at the other end of the car. Both ends of each car are, however, equipped with hand brakes and automatic Westinghouse air brakes (supplied with a pressure

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of 115 pounds per sq. inch, and having the brake shoes bearing upon the top of the wheels). The cars are also equipped with circuit breakers. Each car is lighted with three clusters of 3/16 C.P. lamps each. Five iron pipes, 36 feet in length and four inches in diameter, running under the floor of the car, are used as air tanks, and also serve to strengthen and support the car. Each car is suspended from two bogies, 26 feet apart, each running on two wheels 35 inches in diameter, which are driven by an electric motor of 36 H. P. by means of spur gearing. The motor is fixed between the two

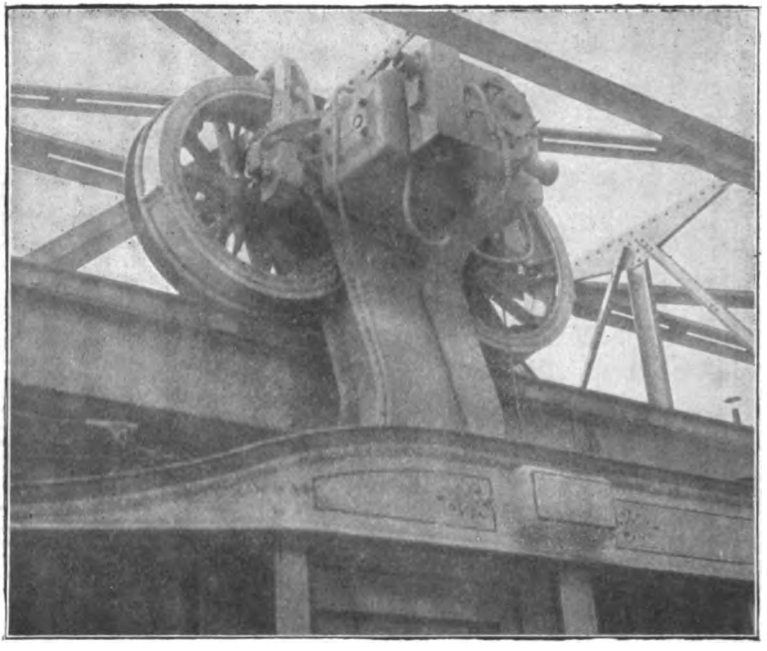

FIG. 11.—Showing method of suspension, motor, etc.

wheels, and is clearly indicated in Fig. 11. The lower part of the hook-shaped bogie frame is adjustable. The round rail heads form a center about which the entire car can oscillate. The bogie frame is just below the girder member, which bears the rail curve to that center, and the gap between girder and frame, only 0.228, is so small that the wheel cannot jump from the rail, and thus the frame would be held tight by the girder should any part break. The structure is about 25 feet above the street level, and the lowest portion of the carriage

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about 15 feet. The weight of the carriage with its load of 50 passengers is estimated as 14 tons, made up as follows:

Two electric motors with complete electrical outfit	6743 lbs.
Two bogies with buffers and cross beams	3960 "
Carriage body with seats, complete	12903 "
Passengers	7700 "
Total	31306 lbs.

This would give a carriage weight, including everything, of 618 lbs. per passenger. The superstructure itself weighs only 700

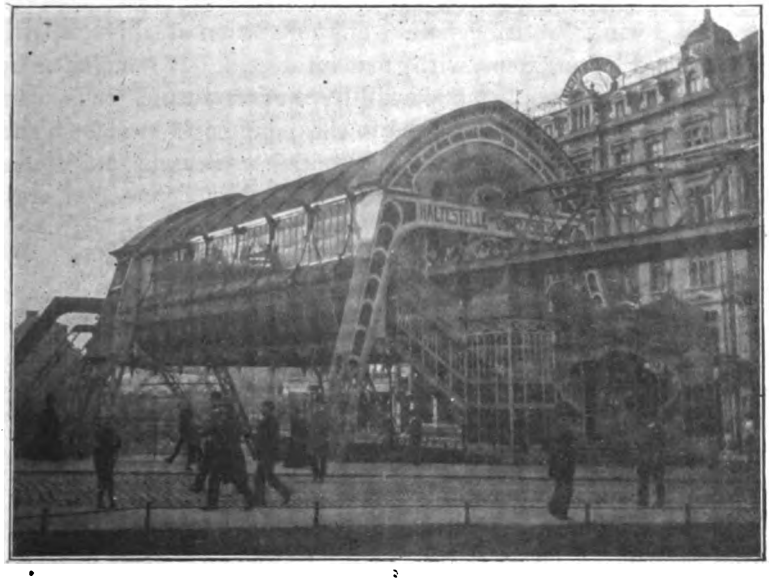

FIG. 12.—Doppersberg Elevated Station.

lbs. per foot. The supports are placed at an average distance of 100 feet apart. It is proposed to run these trains every three minutes, and at an actual speed of 31 miles an hour; the average speed, including stops, will be about 20 miles. With the automatic block signal system installed, they may be safely operated at intervals of two minutes. As already stated, the two electric motors of a carriage are of 36 H. P. each. They may be connected in parallel or in series in the usual manner, and operated at 600 volts. The current is taken off the contact rail, which is fixed to the obliquely fastened insulators, by a contact

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shoe, held by an inclined lever controlled by a compression spring. The contact rail is of iron with a round head, the trolley shoe embracing it and making good contact at any position taken by the carriage. It is estimated that with trains of four carriages, 6,000 persons could be despatched per hour, in either direction. The rails are $4\frac{1}{2}''$ high with a round head, and $2\frac{2}{10}''$ wide with lap joints. It is estimated that it will take two years more to complete the railroad. At the time of my last visit twelve of the 20 stations were already finished, and 26 of the 50 cars completed. Work was started in March, 1898; in January, 1899, a first test of 400 metres was made. On the 24th of October, 1900, Emperor William was given a special trip over $7\frac{1}{2}$ kilometers, from Vohwinkle to Elberfeld. The operation of this road will be followed by engineers with great interest, and it remains to be seen how great an influence it will have upon future transportation problems. I am indebted to the company's engineers and to *Engineering* for the data presented. I understand some 6,000 engineering drawings were prepared in connection with this notable installation.

The Nernst Lamp.

The Nernst lamp is the invention of Prof. Walther Nernst of Göttingen Univ., a leading authority in the chemical world in which his originality had left an important impress before he made his discoveries resulting in the electrolytic lamp. Prof. Nernst informed the author last November at his laboratory in Göttingen, that the discovery of the principles underlying his lamp, had been made during a series of experiments to determine what caused the efficiency of the Welsbach, or as it is called abroad, the "Auer" mantle. More or less secrecy has been observed as to the materials used in the Welsbach mantle, but it is well known that certain metallic oxides, such as thorium, yttrium, cerium, zirconium, glucinum, erbium, and others less known, have entered into their manufacture. Probably the first three mentioned are the ones chiefly used, although the ingredients and proportions have been varied from time to time. These very refractory materials are of a yellowish or a whitish color. They are non-volatile, save at exceptionally high temperatures. Prof. Nernst in his early experiments took certain of these highly refractory substances, such as magnesia oxide mixed with porcelain, which form high-class insulators when cold, but which he found

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were electrolytes when hot. These are termed conductors of the second class, or such chemical substances as are decomposed upon the passage of a direct current. An infinite amount of experimentation has been going on all over Europe and America to find the most suitable substances for these electrolytic filaments, or, as they are termed, "glowers" of the Nernst lamp. According to a recent number of the *Zeitschrift fur Elektrochemie* of which Prof. Nernst is one of the editors, a series of tests have recently been made upon samples of glowers composed essentially of the oxides of zirconium, thorium and yttrium, together with certain rare earths. These glowers were all in the form of thin, straight rods, which required a temperature of 900 to 1300 degs. F., to render them sufficiently conducting to start them operating with the electrical currents. The following table gives the results of six experiments with these samples. The three figures in each case, represent the observations in the beginning and end of the experiments, and the mean values. To obtain the mean spherical candle power, multiply the candle power in the table by .78. The watts given is solely for the energy consumed in the glower itself, and to this should be added from five to fifteen per cent. for the energy consumed in the steadying resistance in series with the glower, which is indispensable in the actual working lamp:

TABLE:

Life (hrs.)	Volts.	Amperes.	Candle power.	Watts per candle.
231	184—191	0.21—0.192	28.5—24.5	1.35—1.50
	186	0.206	28.1	1.37
308	181—201	0.22—0.19	30.5—27.0	1.30—1.42
	190	0.20	29.3	1.35
447	190—203	0.41	64—57.5	1.21—1.45
	188	0.41	58.7	1.37
249	183—205	0.41—0.40	67—70	1.12—1.17
	192	0.40	65	1.20
522	184—196	0.85—1.0	123—130	1.27—1.50
	189	0.96	129	1.41
184	180—192	0.38	57.7—58	1.19—1 26
	184	0.38	53.5	1.31

The efficiency of incandescent illuminants, as far as radiation goes, depends simply upon the temperature. The carbon filament in an incandescent lamp is structurally too weak, and has too low a specific resistance to stand very high temperatures.

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FIG. 14.—Standard Type German "Automatic" Nernst Lamp.

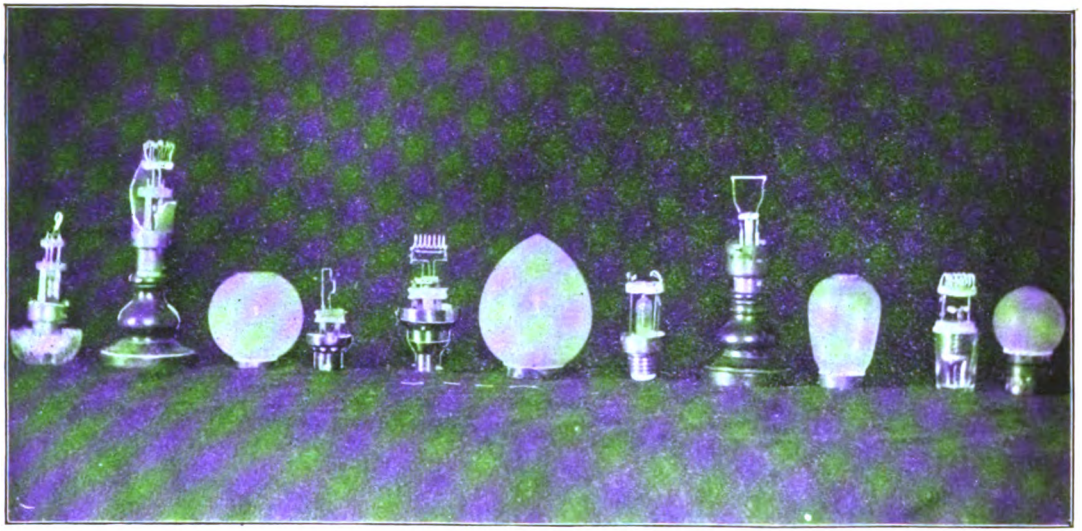

FIG. 13.—European Types of "Torch Lighting" and "Automatic" Nernst Lamps.

FIG. 16.—"Replacement" Piece and Socket (English Type) "Automatic" Nernst Lamp.

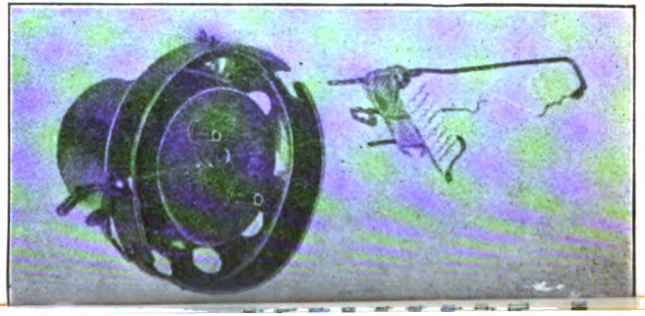

FIG. 15.—"Replacement" Piece and Socket (English Type) "Torch Lighting" Nernst Lamps.

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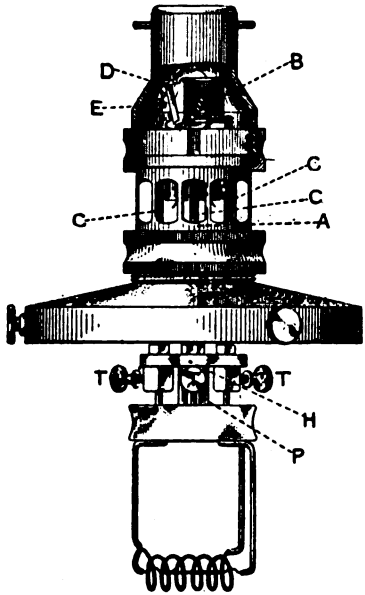
The blackening of the globe of an incandescent lamp is indicative of its rapid disintegration, and of the fact that its highest practicable temperature has been reached. Probably the most refractory substances thus far used as illuminants are zirconium, used to replace the lime in the lime light, and the oxides of the so-called rare earths already referred to, used in the Welsbach mantle and the Nernst lamp. It is a well-known fact that the Welsbach incandescent gas mantle falls off in candle power very rapidly. I believe the loss is about 25 per cent. in the first 60



Part Section.

FIG. 17.—Standard Type English "Automatic" Nernst Lamp. 100 Volts. 50 C. P.

hours. So closely is the composition of the Nernst filament or glower related to the Welsbach mantle burner, that it is an interesting question as to what extent the Nernst lamp will fall off in its efficiency. The greatest difficulty experienced by the manufacturers has been the proper clamping of the filament. I have examined some of the platinum connections after considerable use, and they seemed to have been eaten away, and even the glower itself is slightly diminished in thickness and become crystalline near the anode or positive pole in lamps run on a continu-

NOTE.—Figs. 15, 16 and 17 are republished from the London *Electrician*.

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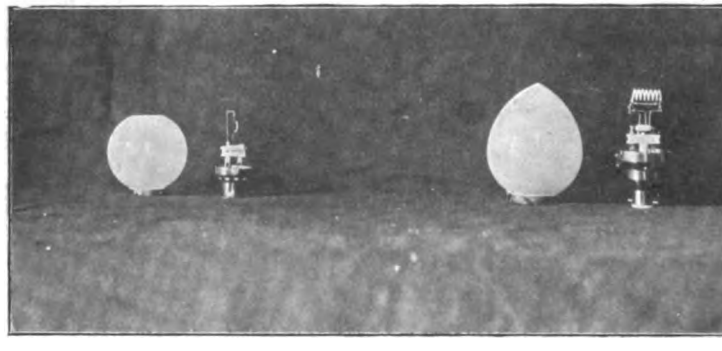
ous current. Many experiments have been made to obviate this difficulty, such as forming a blob of refractory material around the platinum connections, and bringing the platinum wire to the surface to reduce somewhat the temperature by radiation. There seems to have been also considerable difficulty caused by expansion, which the London Nernst Company claims to have obviated by running a platinum wire from the end of the glower through the loop in the supporting wire, enabling the platinum to slide back and forth in this loop. The end of the platinum wire is bent down, and attached to the supporting wire below the loop, and is shown in Fig. 16. The London company states that this has lessened the breakage considerably.



A B

FIG. 18.—English Type "Torch Lighting" and "Automatic" Nernst Lamps.

In Fig. 18 A and in Fig. 15, are shown illustrations of the simplest form of Nernst lamp, of the type manufactured by the London company. This lamp, which is of 16 C. P. at 100 volts, requires an alcohol torch, or a match to heat up the glower at starting; the globe of the lamp is open at the bottom to permit of this preheating. The glower is a tiny white filament scarcely as thick as a common pin, platinum wires wound around the ends attach it to the supporting wires which are of nickel, the junctions to the glower being covered with blobs of a substance similar to the glower body itself; below the glower is shown a triangular piece of unglazed biscuit porcelain, upon which is wound a fine platinum wire called the "steadying" resistance, connected in series with the glower which has a tendency to run to excessive temperatures; and by reason of its rather high negative tempera-

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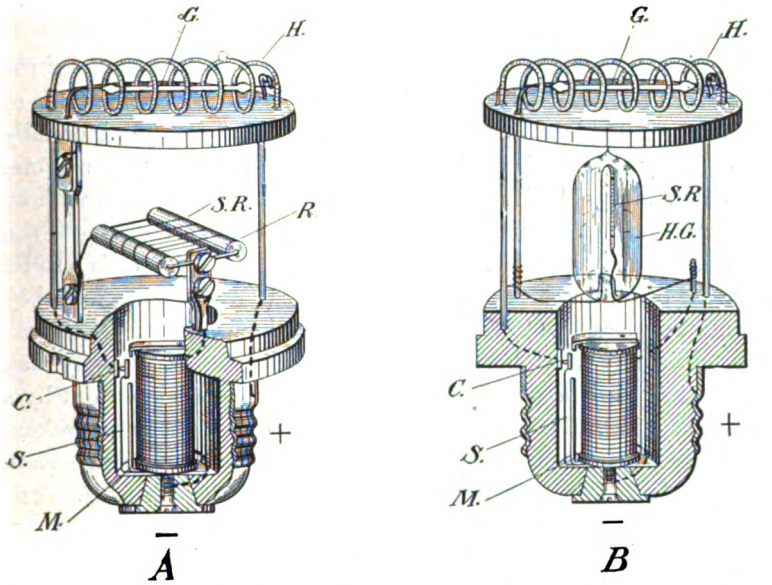
ture coefficient renders such resistance necessary. It will be noted that the porcelain is hollowed out on each of the three sides, so that the platinum which has a large positive temperature coefficient rests only on the edges of the triangle. In the earlier forms it was found that the flat surfaces conducted off the heat of the platinum and it took time to heat up the porcelain and therefore it would not act as an automatic regulator and increase its resistance properly and quickly. The nickel supporting wires already referred to, pass through the triangular piece of porcelain, terminating in eye pieces which engage the hook connections in the



G.—Glower. H.—Heater. S. R —Steadying Resistance. R.—Rods of Porcelain. C.—Contact. S.—Spring. M.—Magnet. H. G.—Hydrogen Gas.

Fig. 19.—Standard Types Automatic Nernst Lamps shown at Paris Exposition, 1900, and as used in Germany.

base of the lamp. Thus the glower and steadying resistance and their supports represent the renewable portion of the lamp—or, as it is called: the "replacement piece." It is illustrated in Fig. 15.

In Berlin and other places iron wire was extensively employed owing to its peculiar properties, and in order to prevent oxidation and make it operate successfully it was employed in an atmosphere of hydrogen gas. Although I saw many lamps employing

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this iron resistance, the tendency abroad now seems to be to do away with its use and employ platinum or some special alloy instead. In Fig. 19, B, is shown a German type of Nernst lamp such as was exhibited at the Paris Exposition in which iron steadying resistance is shown sealed in a glass globe containing hydrogen gas. In Figs. 14 and 19 A, are shown A. E. G. German types of lamps employed in Göttingen and Berlin which show a platinum steadying resistance wound over two rods of unglazed biscuit porcelain, and in Fig. 13, (fourth lamp from right end) is shown a Hungarian type of lamp (Ganz & Co's) where special resistance wires are wound on porcelain tubes attached to both supporting wires of the glower and in series therewith.

In Göttingen—which, by the way, is not only the home of the inventor of the Nernst lamp, but enjoys the additional distinction of being the first place in which the Nernst lamp was commercially used (they claimed to have 300 in use). I found a hotel in which lamps had been employed of the type heated with an alcohol torch, where their use had been discontinued owing to the annoyance caused each time they were lighted. There is also an element of danger from fire in this type of open lamp, and they cannot be placed where subjected to a strong draft. Remarkable as it may seem, here is an electric light which not only may be lighted with a match, but which may also be blown out by a breath of wind. This type of lamp is much more apt to be broken. It would of course be unsuitable for use in mines, or in certain places where the carbon incandescent lamp can be used. The self-igniting lamp is naturally more complicated and more expensive, but it is self-evident that it is the lamp which must be used as a rule. Nernst lamps of this type are illustrated in Figs. 16, 17, 18 B, and 19.

To explain the operation of the automatic or self-lighting type of lamp, when the current is first turned on, the heating coil shown in Fig. 19 is alone in circuit, as the glower, steadying resistance, and cut-out magnet, which are all in series, form a shunt around it of infinite resistance; the current passing through the heating coil soon makes it red hot. The glower or filament of refractory material is heated by radiation and convection, from the coil; until its resistance lowers sufficiently for it to become a conductor of electricity, (four glowers of different C. P. are shown in the foreground in Fig. 13). The moment this happens the current also passes through the tiny electro-magnet inside of the lamp base shown in

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Fig. 19 A and B, and which is in series with the glower, and which, in attracting its armature to it, opens the circuit of the heating coil leaving the filament or glower only in circuit with its regulating or steadying resistance and the magnet winding. It takes approximately 10 seconds for the lamp to light up after the circuit has been closed, although I have frequently timed lamps where they have taken as high as 40 seconds to light up. It is stated that the glower of the Nernst lamp must be heated to 700° C. before it becomes a conductor of electricity. The "heater," as it is called, consists of a thin cylinder of porcelain, around which is wound a very fine platinum wire, perhaps .03 to .04 mm. in diameter. The cylinder is then dipped in liquid porcelain, and after drying is bent in a spiral form by wrapping it around a rod while it is being heated by means of a blow-torch. There are usually from five to seven turns in this spiral.

The perishable portions of the Nernst lamp—*i. e.*, its glower, the heater and resistance—are constructed so as to be easily detached, as in the case of the non-automatic type of lamp, and can be replaced at from one-quarter to one-third of the price of the lamp, so that while the original cost of the lamps is greater than the carbon lamps the replacement cost is less. Replacement pieces for both torch-lighting and automatic types (English) are shown in Figs. 15 and 16. The electro-magnet will of course last indefinitely. In the replacement piece of the London company's lamp, a compression-spring contact is used for one connection in conjunction with two eye pieces of different lengths, which engage two hooks in the lamp base, one long and one short; this makes it impossible to wrongly connect up the lamps.

In the German type of Nernst lamp, illustrated in Fig. 14, and in Fig. 19, the glower is placed in the center of the heating coil. In the London company's type, shown in Fig. 18 B, the heating coil is placed below the glower or filament; in others (see Figs. 16 and 17) it is in the center of the spiral, as in the German type.

The London company were for a long time puzzled in their endeavors to get rid of the buzzing noise of the cutout magnet when operating upon alternating current circuits. It was finally found to be due to the air confined back of the armature, by reason of the form they employed; by cutting the iron away a trifle this was entirely obviated.

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The company is now standardizing lamps for 8, 16, 32 and higher candle power for circuits of 100 volts and upwards.

The 220-volt lamps are usually made of 25, 50 and 100 c. p., although I saw some at Ganz & Co's works at Budapest and elsewhere of as high as 160 c. p., which were being tested experimentally.

All of the lamps which I saw in Europe were run on a 200 to 220-volt circuit, excepting a few I saw in London on 100-volt circuits, and as a rule 25 c. p. lamps were used.

In the large types of lamps it was found that the magnet coil was frequently burned out from over-heating, and to obviate this the shell of the socket was perforated, which, however, exposes the connections to some risks of short-circuits, and the present form will doubtless soon be altered.

The fine iron wire connected in series with the filament, which has been considerably utilized in the past, has usually been of about .019 mm. in diameter. This iron wire and platinum wire, which has so exfensively taken its place, is used because of the glower lowering its resistance so rapidly when the temperature increases. A very slight variation in the voltage increases very much the candle power of the filament and the strains upon it. The wire is so proportioned that with about a normal current it is heated to a range of temperature of about 450 to 500° C, at which iron has a very rapidly rising temperature characteristic—that is, its resistance increases very rapidly with an increase of temperature caused by an increase of current. Being in series with the filament, a total resistance, which determines the amount of current supplied to the lamp, will be the sum of the glower and of the iron steadying wire, and as one decreases with increase of temperature, the other increases and compensates for it, keeping the sum approximately constant. The iron resistance absorbs about 10% of the voltage. As pointed out by Prof. Nernst and Dr. Spies, according to the law of Kirchoff, all opaque bodies emit more calorific than luminous rays, furnishing what is termed the normal spectrum of an opaque body, but according to the well-established electro-magnetic theory of light all conductors of electricity are of necessity opaque to luminous radiations. It is to be expected, therefore, that as long as electrical conducting materials are used as light-emitting substances in lamps, the bulk of the energy expended upon them will be wasted in thermal radiations and only a small portion will be transformed into luminous radia-

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tions. It is impossible to make an efficient lamp with such materials except under the conditions of working at the temperature of the electric arc.

At the Paris Exposition the A. E. G. made an interesting exhibit of the Nernst lamp, and advertised that it had an efficiency of 1.6 watts per candle power, a life of 200 to 300 hours, an E. M. F. of 220 volts and from 25 to 50 C. P. Mr. James Swinburne, in his lecture before the Society of Arts, February 8th, 1899, stated the watts per candle for small lamps, including the steadying resistance, as 1.5 and for large lamps as 1.6. At present the London company, with which he is connected, state that their Nernst lamp has an efficiency of 1.7, including the resistance in series with the filament.

There is undoubtedly a large field for the application of lamps of the Nernst type between the field occupied by the 16 to 50 C. P. incandescent lamps and the arc lamp, and it lends itself to decorative effects equally well with the incandescent lamp. The C. P. of arc lamps is something that has never been satisfactorily determined, and it has not infrequently been the custom in judging the C. P. of arc lamps to "guess at it and multiply by four." In C. P. steadiness, color of light and ability to throw the light down where it is needed and in requiring less attention, the Nernst lamp will doubtless prove superior to the arc lamp. There will be little difficulty in making lamps of the Nernst type of very high C. P. by employing longer filaments, or preferably a number of filaments in series or multiple series, and potentials of 500 to 1,000 volts may thus be employed. Promising as the Nernst lamp undoubtedly is, it will probably by reason of the difficulties in the manufacture of the lamp be a long time before the carbon lamp is entirely displaced, if it ever is.

Dr. Otto F. Blathy, Director of Ganz & Co., Budapest, Hungary, who together with Eggers & Co. control the Nernst patents for Austria and Hungary, told the writer recently in Budapest, that when the Nernst lamp became a commercial article, there would be no more arc lighting. He said that tests made by them showed that for a given number of watts the efficiency of the Nernst lamp was greater than that of the arc lamp, presumably meaning the spherical C. P. Mr. James Swinburne in his lecture, said: "Once the 'Nernst' becomes so general that systems of distribution are laid out to suit it, instead of to suit the carbon lamp, the carbon lamp is 'practically out of running.'"

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In this connection it will be remembered that with the advent of the Edison carbon filament incandescent lamp, it was believed that gas as an illuminating agent was doomed, whereas it has been shown that the incandescent lamp exercised a stimulating and beneficial influence upon the gas light, which is more extensively employed to-day than ever. The tendency of all great inventions is rather in the line of building up than tearing down.

It is impossible to operate the Nernst lamp in a vacuum, at all events where a direct current is employed, as being an electrolytic lamp, it is said to be necessary to admit oxygen to re-oxidize the magnesium liberated at the cathode. Where continuous currents are used in electrolytic lamps of the Nernst type, the liberation of ions at the connections produces a serious difficulty. I heard it claimed by some while abroad that the lamp operated more satisfactorily with a continuous current. Others, however, were positive that an alternating current was preferable. One prominent engineering authority went so far as to state to me that he did not believe that the lamp would be a commercial success, except when operated from a storage battery. In one place in Göttingen, which installation employs Körting gas engines and storage batteries, I was told that ten lamps of the self-lighting type had been installed, and in four hours they were all burned out. The actual results at Göttingen where they have about 300 lamps burning, show, I believe, that the open type of lamp did not last over 200 hours, and the automatic or self-lighting type did not last over 100 hours. While I was at Göttingen, a telegram arrived from Berlin requesting the return of all of the new automatic or self-lighting lamps sent them a few days previously (some 300 in number) as there was something the matter with them. As they had already put out about 50 of them, this could not be done. This would serve to indicate that even after the several years of experimenting, the A. E. G. who were the parent company, had not yet succeeded in making a lamp which was a thoroughly commercial article. During the past six months, I have seen the Nernst lamp burning in the following places: Paris, France; Munich, Bavaria; Budapest, Hungary; Berlin and Göttingen, Germany, and London, England, and my own impression is that the American type will shortly lead the way.

The A. E. G. have been for several months past putting out lamps in Berlin. They charge a rental or royalty of three

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marks (about 72 cents) per year, and 30 pfennigs (7.14 cents) for renewals.

The lamp globe holder and the butt which fits into the socket are sealed together by a lead and wire seal. I was informed that any of these lamps having the seals broken or any lamps which were carelessly broken, had to be repaid for at the rate of three marks each (about 72 cents.) I was also informed that the users were compelled to give a receipt for the lamps, and every effort was made to prevent the lamps from getting into the hands of other people, and to prevent their being examined.

The Nernst lamp gives a most pleasing light; in color it stands midway between the yellow and red rays of the incandescent carbon lamp and the violet and blue of the arc lamp; it is, however, so dazzlingly white that it is, as a rule, placed in ground glass globes, thus securing much greater diffusion; with a loss in the light probably not exceeding 15 to 18 per cent. I watched carefully the 54 Nernst lamps installed by the A. E. G. in the Café Bauer in Berlin, this being one of their first installations, and the light certainly produces a much more pleasing effect than the carbon incandescent lamps (used in certain places in the same fixtures) and is also superior to the Welsbach mantles used in the same rooms. Arc lamps are also burned in front of the café, so that in this one installation four types of lighting were employed—three of them being electrical.

During my three weeks stay in Berlin, I observed carefully every evening the 54 lamps which were here installed, and which were doubtless on account of their prominent position, of the best type made by the A. E. G. and I noted that there were usually from two to four or five lamps out, and even at times as high as eight or nine out, however with an efficiency approximately half that of a carbon filament lamp a much shorter life may be permissible. It was also quite common—both in this installation and others, especially at the Paris Exposition, where the A. E. G. exhibited about 300 lamps, to see the lamp running with the heating coil in circuit, giving a dull and sickly light.

I have endeavored to give the facts about the Nernst lamp development as observed by me during my recent sojourn abroad of over five months. I have no desire to disparage this remarkable and most promising advance in the electric lighting field and well do I remember when an assistant at Mr. Edison's laboratory at Menlo Park, N. J., in the incipient stages of the de-

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velopment of the Edison carbon filament electric lamp, the difficulties met with; which at times seemed insurmountable. There were novel and knotty problems to solve such as the modern incandescent lamp manufacturer knows not of. Personally, I have no doubt of the ultimate solution of the knotty and peculiar problems met with in the manufacture of the Nernst lamp, nor of the immense value this invention will ultimately reach to the owners and the world at large.

In conclusion, without going fully into the history of the art; reference should be made to the work of Jablochkoff, who in 1878 made use of sparks from an induction coil passing from one of the parallel carbon pencils of his "candle" to the other, and thus heating up the kaolin insulator placed between until it became a conductor, and the arc once established remained; being supplied by the dynamo current.

He subsequently used a piece of carbon mixed with syrup at the top of the candle which a current of 100 volts heated until the kaolin became a conductor and the arc was supported.

At the Paris Electrical Exposition of 1881 and in the following year in London, the "La Soliel" lamp was shown in which the arc was formed by drawing rods or wires across the face of a block of marble until it became heated sufficiently to conduct the electricity, when it became incandescent and gave a most beautiful light.

Demonstration:—The author here proceeded to show a number of Nernst lamps burning; illustrating how simply they could be ignited by means of a match and by an alcohol flame; and after they had been burning for some time, showed how they could be blown out by blowing upon and cooling the glower. He also placed a lamp of high candle-power in front of a fan motor to show how readily it would be extinguished, or as he expressed it, "how easily it would catch cold." He also exhibited quite a number of the various types of German, Hungarian and English types of torch-lighting and automatic Nernst lamps and glowers of various candle power in a glass case and showed samples of Mr. Longhan's di-carbide of calcium lamps burning.

The Osmium Lamp.

During my stay in Vienna last October, through the courtesy of Director Gallia of the Auer Company, I was permitted to see several of the new "osmium" incandescent lamps burning, and

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although I was unable to secure full particulars about this new and interesting development I learned that the lamp, which is the invention of Dr. Auer von Welsbach, operates at an E.M.F. of 25 volts and shows an efficiency of from .9 to 1 watt per candle. The three lamps which I saw in use were all connected in parallel and operated with key sockets, and differed but little in general appearance from an ordinary carbon filament lamp. The globe was somewhat longer than an ordinary 16 C. P. lamp, and the filament, which was of the hairpin shape, was much longer. It must be used in a vertical position, owing to its flexibility. I was told that these lamps had shown a life under test of 700 to 800 hours. It will be interesting to learn to what extent the low voltage of the lamp and the rarity of the material used in its manufacture will affect its commercial application. It had been intended to show the osmium lamp at Paris before the close of the exhibition, but there was not sufficient time. "Osmium," which was discovered by Tennant in 1803, is a blue-white metallic element and is almost infusible. For a long time it was known only as a crystalline grainlike material; and when fused in the electric arc, as a hard brittle substance unfit to be worked. I was informed in Paris, where I first heard of this lamp, that the successful method of handling this material, which has always been most difficult to work with, was due to a large extent to Mr. Waldron Shapleigh of the American Welsbach Company, which concern controls the patent rights for the United States. According to Engineer Scholz in his lecture before the German Incandescent Gaslight Co., on Jan. 23, 1901, an osmium lamp after burning 1,500 hours was still intact, and had fallen off in candle-power but 12 per cent.

Its efficiency at starting was 1.45 watts per C. P., and at the end of 1,500 hours was 1.7 watts. It is claimed that as long as the filament remains intact it can be renewed several times. While the present range of voltage for these pure osmium lamps is 25 to 50 volts, a number of filaments can be connected in series or multiple series for higher potentials, and it is proposed to increase the resistance by coating or uniting the osmium with certain oxides. Mr. Scholz refers to a test conducted upon 4-25 volt osmium lamps in series, and 4-100 volt carbon lamps in parallel, the osmium lamp showed a consumption of 0.96 amperes, and the carbon lamp 2.40 amperes, the former effecting a saving of 60 per cent.

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A 20 C. P osmium lamp run at 27 volts required 24 watts, and a 20 C. P. carbon lamp required 68 watts, the former effecting a saving of 44 watts, or about 35 per cent.

The osmium lamp was much the coolest, by reason of its higher efficiency. I had hoped to be able to show you an osmium lamp this evening and give some fuller data, but was unable to do so. I have brought with me a number of the foreign types of Nernst lamps for your consideration. I have, also, several dicarbide of calcium lamps, which type have been manufactured to some extent abroad. They are the invention of Mr. Langhans, of Berlin, to whom I am indebted for them. They are shown in Fig. 20. It may interest some of our members to learn that the Allgemeine Elektricitäts Gesellschaft of Berlin, are now

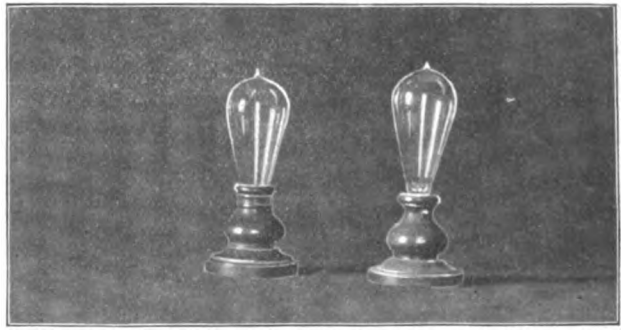

FIG. 20.—Laughan's Di-carbide of Calcium Lamps.

making all their carbon filament lamps without platinum leading-in wires, using, so I have been informed, iron wire, the sealing being done in an atmosphere of carbon monoxide. The A. E. G. purchased the patent from Schott, the well-known glass manufacturer of Jena. I have been presented with one of these lamps, but it did not arrive in time to show it to-night. I am told these lamps give out quickly, diminishing to a dull red. In London I found a company which has been formed for the purpose of "rejuvenating" incandescent lamps. The filaments which have gone off in efficiency and candle power are taken out of the globe and retreated, the globe cleaned of its smoky deposit and the lamp resealed and re-exhausted. I did not learn just how the globes were to be cleaned or what the rejuvenation was to cost. There are also several lamps known as

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"watt" lamps being exploited in Europe. They have a high efficiency, and are very simple, and cheaply constructed, and have a life of perhaps 200 to 400 hours. They make no pretense of being long-burning, but rely upon their high efficiency and low first cost.

The Steam Engine and its Competitors.

M. Berthelot, the Chief Chemist of France, and Member of the French Academy to represent science in that body, has recently declared himself against the utilization of steam, which, he declares, is already becoming obsolete, and gives it as his

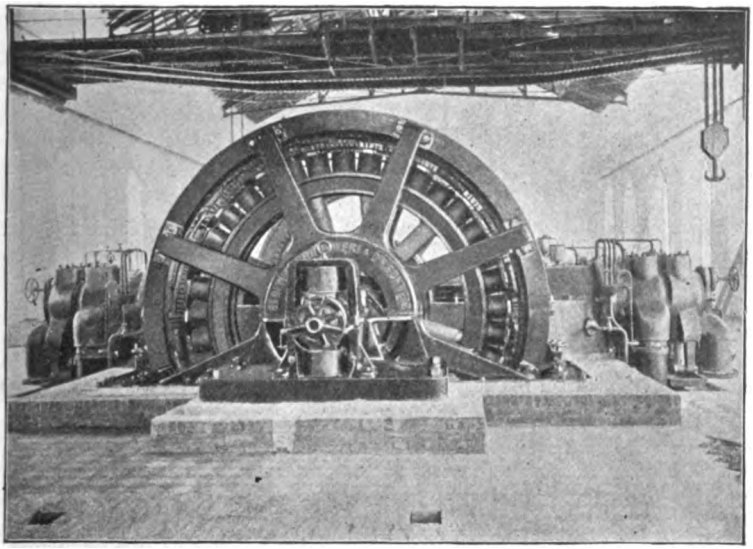

Fig. 21.—Three-phase Generator direct connected to 650 H. P. "High Furnace Gas" Engine.

opinion that the future of motive power belongs to gas and petroleum, and that the steam engine will be relegated to museums where other anthropological curiosities from the Stone Age down, are collected.

In December last, in opening a discussion on Mr. H. A. Humphey's important paper, entitled "Power Gas and Large Gas Engines for Central Stations," delivered before the Institution of Mechanical Engineers of Great Britain, Dr. Mond, the well-known chemist and inventor of the Mond Gas Process, stated that the paper which had been presented, appropriately marked

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the closing of a century of steam as a motive power, and the opening of a century of gas as a motive power.

The author, while in London several months ago, in speaking upon this subject with Prof. John Perry, F. R. S., and asking for an expression of his views, was told by Prof. Perry that with the development of large types of gas engines, there was no doubt in his mind but that the steam engine would ultimately be very largely supplanted.

In response to a request for an opinion upon this subject, Prof. R. H. Thurston has sent the author a letter which by reason of its very great interest is published *in extenso*:

ITHACA, N. Y., February 22d, 1901.

MR. WILLIAM J. HAMMER,
New York.

My dear Mr. Hammer:

Yours of the 21st is received, inquiring about the relative efficiency of the steam and the gas engine.

The best work, to date, is practically the same for both engines. Each has delivered the net horse-power with a consumption equivalent to about one pound of good coal. The consumption of such fuel for efficiency unity would be about one-fifth of a pound per horse-power, and these engines have thus both attained an efficiency, between the coal pile and the point of delivery, of about twenty per cent.

The steam engine has attained so nearly its limit that further progress under commercial conditions would seem to be likely to be hereafter very slow and to be dependent mainly upon the possibility of increasing the thermodynamic efficiency by extending the thermodynamic range of working temperatures. In the steam engine, this range may be increased either by still further increasing the working pressure at the boiler or by superheating the steam or by both expedients combined. Higher pressures are coming to be available, with progress in the construction of high pressure, presumably water-tube boilers, and we have, in Sibley College work, employed over a thousand pounds without special difficulty and I have no doubt that we can quite as well as did Perkins, two generations ago, use pressures of two thousand pounds and probably more. We are now beginning to find practical methods of construction and use of superheaters for ordinary pressures, and I have little doubt that we will be able to superheat steam of those higher pressures in course of time. These improvements should permit the increase of efficiencies by something like fifty per cent. and bring the consumption of fuel down to three-fourths of a pound of good fuel per horse-power hour, and perhaps within the next generation, if not within ten years.

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I am not prepared to say what should be hoped for with the gas engine ; but the indications at the moment would seem to be that, as we have a very much larger opportunity to reduce wastes that now characterize the gas engine than to extinguish those affecting the steam engine, more should be expected from the coming years with the former than with the latter. The gas engine has only now come to be a formidable rival of the steam engine and is gaining upon it rapidly. The deduction seems fair, therefore, that the next few years should see the gas engine so much improved as to permit it, for many places and purposes, to become a successful rival. In some directions, as at sea, in the locomotive, and perhaps in some other departments, it is possible that steam may continue to hold its place unchallenged, but this is by no means certain.

It is unquestionably the fact that to-day the gas engine is steadily overhauling the steam engine and as steadily displacing it in many directions. I think it extremely possible that it may ultimately displace it very largely, but I think that the steam engine is likely to hold a place among economically available prime movers for a long time to come, and no one can say what may be anticipated to follow its further improvement by effectively combining a maximum range of pressure and a maximum range of coincident temperature, the one giving maximum mechanical efficiency and the other maximum thermodynamic, the combination yielding what is the main object of selection in practically all cases—production of power with minimum costs on all accounts, production of power with least reduction of dividend-paying capacity.

Yours very truly,

ROBERT H. THURSTON.

It seems quite clear from the above and similar expressions one hears from those qualified to speak, that with all the progress that has been made in steam engine practice, in the utilization of higher steam pressures, superheated and reheated steam, condensing, multiplying of cylinders, improving of boilers, etc., that they will no longer satisfy the demands for an economical source of power, and in this country and all over Europe, a very large amount of attention is now being given to the development of gas engines of large power, and to the development of improved types of petroleum, oil, benzine, and other promising motive agencies, such, for instance, as the sulphur dioxide gas or "$S O_2$" Engine, of which I shall have occasion to speak later. The steam engine up to the present has been able to more than hold its own, by reason of its universal adaptability, and its reliability, even with its comparatively low thermal efficiency. During my recent trip in Europe, I visited many of the largest plants for the manufacture of gas engines, and saw large numbers of gas engines in process of construction and in operation, ranging from 250 to 1200 H. P. each. Types of these engines are shown in Figs. 21, 22, 23, 24, 25, 27, 28 and 29. Still larger

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ones are under process of construction at the present time. As indicative of the important work going on in this direction, Fig. 22 shows one bay in a shop of a European manufacturer of gas engines. Various types of these engines I will describe later in the paper. One of the most promising developments, and one which will doubtless enable steam to hold its own to a considerable extent, is the steam turbine now being manufactured in

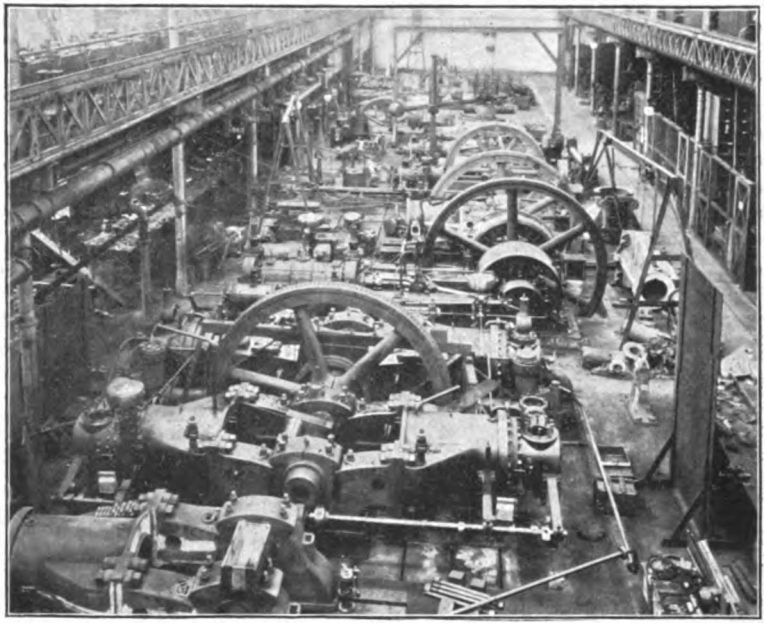

FIG. 22.—Big Gas Engines (Korting) under Construction.

large sizes, both in this country and abroad, and which, by reason of its very great simplicity, slight depreciation and high thermal efficiency, constitutes a steam engine applicable to a very wide field of usefulness and a formidable competitor of the reciprocating steam engine. The Parsons and de Laval types of steam turbines are extensively used abroad, and are being rapidly introduced in this country, where the Curtis steam turbine is also giving most promising results.

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Utilization of "High Furnace" Gases and Big Gas Engines for Electrical Purposes.

The utilization of high furnace or blast furnace gases marks an epoch, not only in the employment of gas engines of great power but in the supplying of a new field for the application of electrical machinery. It is estimated that a blast-furnace having a capacity of 100 tons of pig-iron per 24 hours, produces 7,000,000 cubic feet of gas daily, equivalent to 2,800 H. P. If we deduct the power required to drive the furnace proper, there remains 2,000 H. P., which, so far, have been entirely wasted and which, it has been found may be successfully utilized in gas engines, and it appears that only one-sixth to one-quarter as much gas is required as would

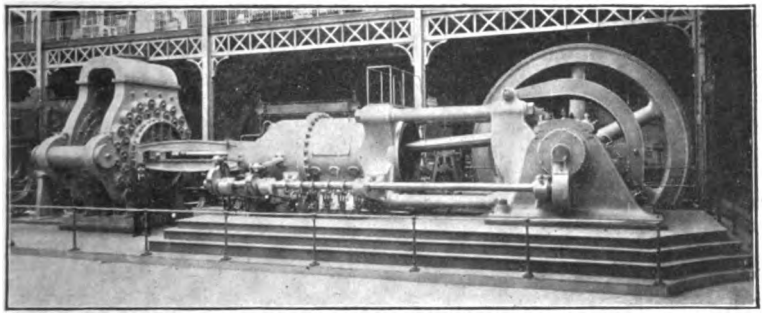

Fig. 23.—1,000 H. P. Gas Engine of John Cockerill Co. of Seraing, Belgium, shown at Paris Exposition. (Connected to double-acting blowing cylinder).

be necessary, when burning the same gases under boilers for producing steam power and furthermore enables us to dispense with costly boilers. Between 25 and 30 years ago it was customary to burn these gases at the top of the stack. They are even so burned to-day to some extent. They were thought to be too poor in quality, and too variable in composition; too full of dust; particularly metallic particles, tending to clog and injure the moving parts; too full of acid matter, and of too high a temperature to enable their use in gas engines; but means have been found by passing the gases on their way from the stack to the engine through pipes and dust pockets in which the particles settle, and through coke and water scrubbers and saw-dust, so that the temperature is lowered, and the gases sufficiently well cleaned. Even at the Friedenshütte Iron Works which I visited in upper Silesia, they

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operated successfully with gas charged with 40% of zinc dust, which only required more purifiers. Although some analysis show the presence of sulphuric and phosphoric acids and chlorine, the alkalies and lime probably neutralize their effect, and there is no apparent corrosion. There is little trouble from variations in quality, and gas works well in a gas engine of a quality which ignites with difficulty under a boiler. The first application of the high furnace gas was made in February, 1895 at Wishaw Iron Works, near Glasgow, with a 20 H. P. gas engine, which indicated 15 H. P. when driven with these gases. During the same year high furnace gases were applied on an eight H. P. engine at the Cockerill Iron Works at Seraing, Belgium, and at the Hörde Iron Works in Westphalia, Germany, where they were used in a 12

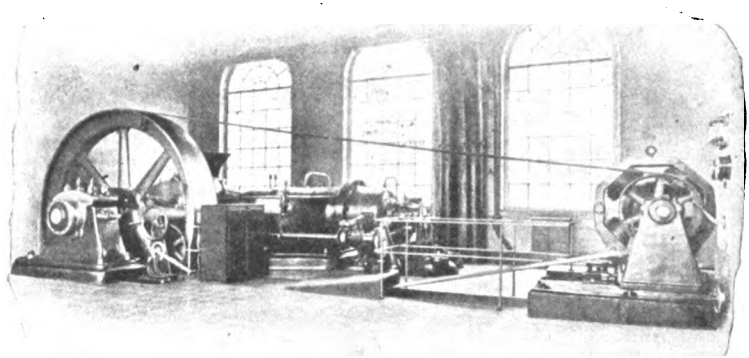

FIG. 24.—Cockerill Gas Engine at Seraing, Belgium, which ran night and day for over two years without stops.

H. P. engine. The first patent for the utilization of high furnace gases in gas engines was taken out the previous year, in May, 1894, by Mr. B. H. Thwaite of England. The high furnace gases are similar in quality to the forms of producer and power gas made by Dowson and other processes, and taken directly from the stack, contain as a rule about 27% of combustible gases, chiefly carbon monoxide, and a little marsh gas and hydrogen; the balance being mainly (about 57%) inert nitrogen. It is estimated that at the blast furnaces in England alone, over 2,000,000 H. P. is annually going to waste, which might be utilized for electrical purposes. The gas engine industry is about 30 years old. During that time, one company, the Otto, has sold in England and Germany alone about 37,000 gas engines, approximating 500,000 H. P. As indicating the development of the large gas engine industry, it is

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interesting to note that the Cocekrill company of Seraing, Belgium, and its licensees, has sold in less than a year, 70 engines of the Delamare, Debouteville & Cockerill system, such as are illustrated in the 1,000 H. P. "Simplex" engine, Fig. 23, which is shown connected to a large double-acting blowing cylinder at the left. This engine develops 650 H. P. when employing high furnace gases. The engine cylinder is 4′ 3″ diameter by 4′ 7″ stroke. The diameter of the air cylinder is 5′ 7″ by 4′ 7″ stroke. The length of connecting rod, connecting two cylinders, is 14′ 5″, diameter 11.8″. Tested without blowing cylinder, this engine showed 573 B. H. P. with a consumption of 123.7 cu. ft. of gas per B.H.P., or with a mechanical

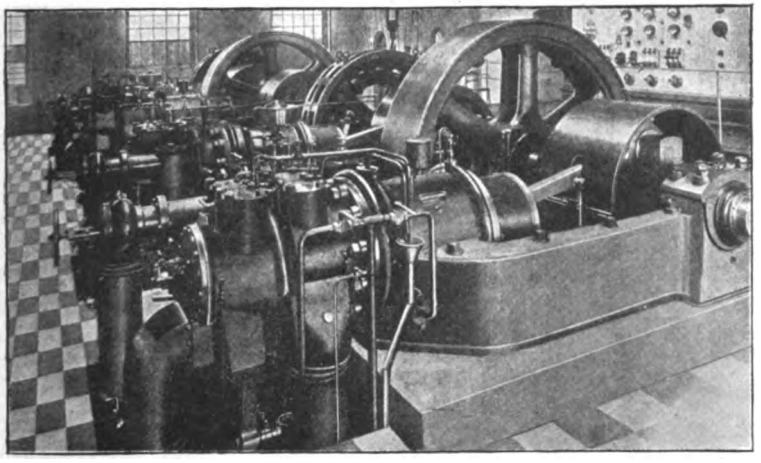

FIG. 25.—A Section of the High Furnace Gas and Electrical Plant at Friedenshütte, Upper Silesia, Germany.

efficiency of 72%, and a thermal efficiency taking the B. H. P., of 20%. With the blower connected, this engine showed 886 ind. H. P. and 725 B. H. P., with a gas consumption of 101 cu. ft. per B. H. P. hour, and a thermal efficiency taking the ind. H. P., of 31.5%. Until recently the speed of these blowers has ranged from 50 to 60 strokes per minute. An ordinary gas engine runs at a speed of 100 to 150 revolutions per minute, according to its size, and giving its maximum efficiency at maximum speed. (According to Kennedy and others a gas engine at one-half load consumes 25% more gas than at full load). I saw recently at Falvehütte in Upper Silesia, Germany, a plant equipped with Horbiger and Rogler valves, enabling these blowers, which in this case were operated by steam generated by furnace gas, to operate at a speed of 80 strokes per

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minute. There are several types of valves now on the market, which enables these blowers to be run at a speed, adapting them to be driven successfully by large gas engines.

As an illustration of the great increase in the reliability and the

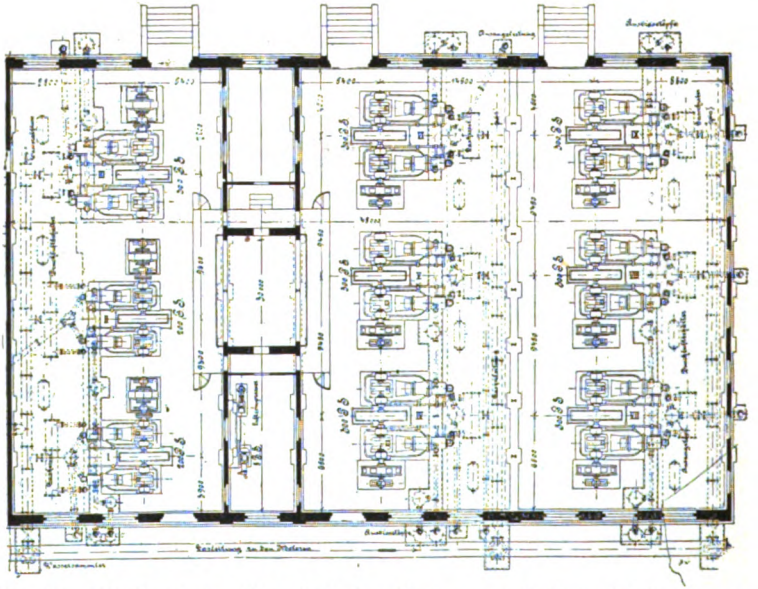
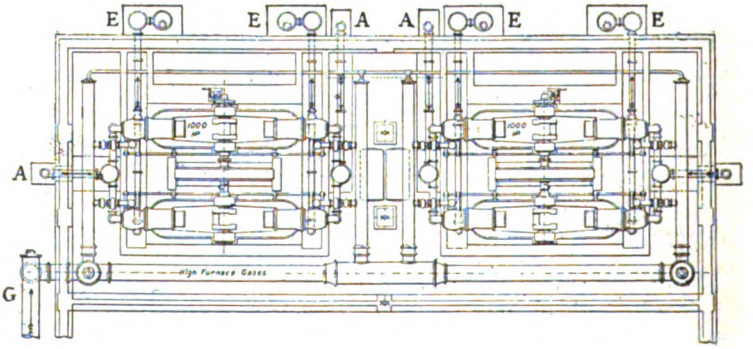


FIG. 26.—Friedenshütte Electrical Installation employing "High Furnace Gases." (2,400 H. P when completed).



A.—air. G.—gas. E.—exhaust. M.—gas and air.

FIG. 27.—1,000 B. H. P. Otto-Deutz Gas Engine.

simplicity of the modern gas engine, I call attention to the engine shown in Fig. 24, which I had the pleasure of seeing at the Cockerill Works at Seraing, Belgium. It has been running steadily for over two years, both night and day, operating with high furnace

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gas. Prof. Aimé Witz' test showed an average of 181 B. H. P., and it showed a mechanical efficiency of 85 per cent., and consumed 116.5 cubic feet of furnace gas per B. H. P. hour. The thermal efficiency taking the B. H. P. is 20 per cent. The speed is 105 rev. per minute. The cylinder has a diameter of 31.5″ by 39.3″ stroke. Fig. 25 is an illustration of a portion of the gas and electric plant at Friedenshütte Iron Works in Upper Silesia, operated by high furnace gases. At the time of my recent visit to this installation, it consisted of two 200 H. P. gas engines direct coupled to two direct current dynamos, and two 300 H. P. gas engines direct coupled to two alternating current dynamos. The gas engines are of the Otto-Deutz type, driving Shuckert dynamos. They were supplying a couple of hundred arc lamps, and several thousand incandescent lamps, and electricity for power purposes. The total H. P. was 1,000, and at the time of my visit this was being increased to 2,400 H. P. The plant, Fig. 26, shows the entire installation as it will be in operation shortly, consisting of six 300 H. P. engines for power purposes, and three 200 H. P. for lighting. In Fig. 27 is shown an Otto engine of 1,000 H. P. built by this company at Deutz, near Cologne. There are four cylinders of 250 H. P. each coupled direct to a dynamo, the open ends of the cylinders facing one another on either side of it. At these works, I saw many gas engines of great power under construction.

The New Körting Two-Cycle Gas Engine.

In Fig. 28 is shown an illustration of the new two-cycle Körting gas engine of 650 H. P., manufactured by Gebr. Körting, at Körtingsdorf, near Hannover, Germany. This concern, which has long been in the gas engine field, is now building engines of 1,000 H. P. and over; of the 4-cylinder 4-cycle type, as shown in the foreground of Fig. 22, for use with high furnace gases for driving dynamos, air compressors, exhaust fans, etc. In Fig. 28 is shown Körting's most interesting new type of 2-cycle gas engine. This engine, which I saw running in their works during my recent visit, consists of a single working cylinder, containing a driving piston, on each side of which the mixture of gas and air is alternately admitted, exploded, and does its work, reproducing steam engine conditions. Remarkable uniformity of speed is secured by this engine; in fact it is doubtful if it is equalled in this respect by any other type of gas engine at present on the market. Exhaust ports are situated in the center of the cylinder. The

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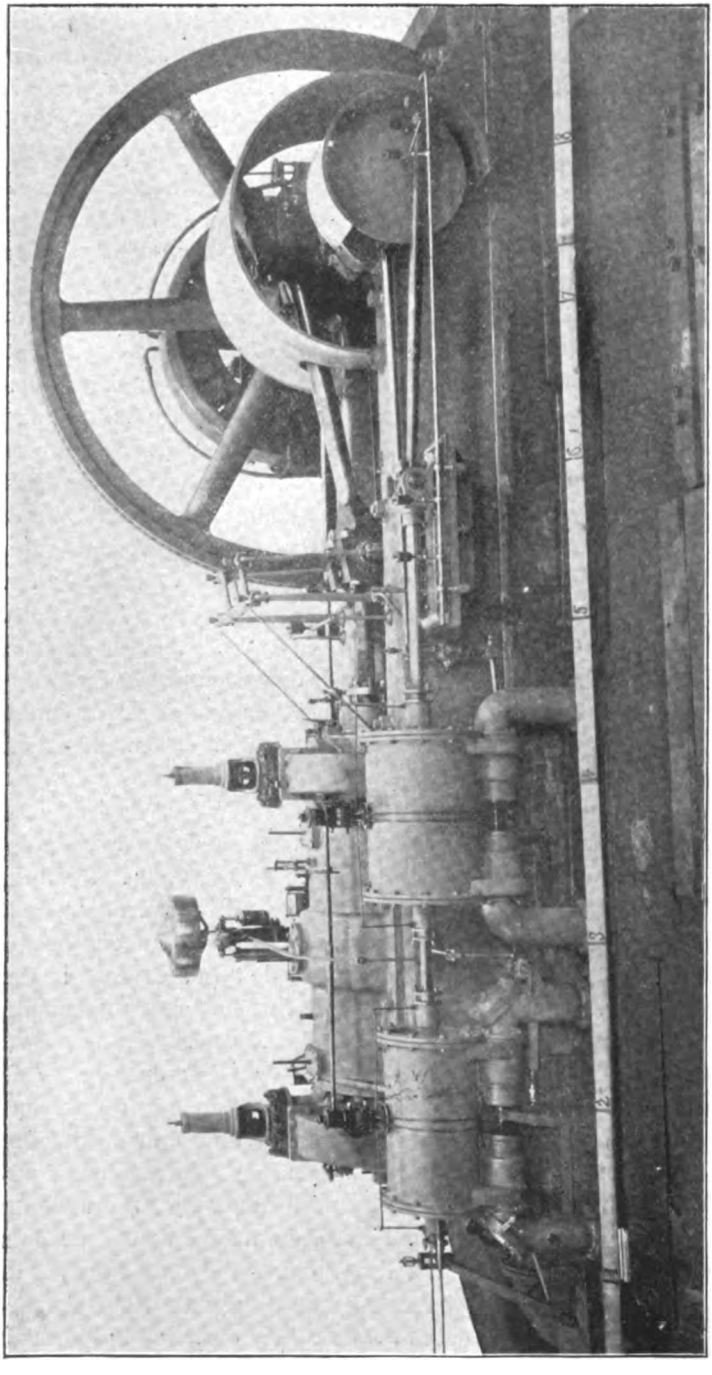

Fig. 28.—Körting Bros. new 2-Cycle—650 H. P. Gas Engine. (Two Twin Engines of this type, of 1,000 H. P. each under construction.)

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piston itself acts as a slide valve to open and close these ports, when it moves in the zones of the dead point at the end of each stroke. Although there is an explosion of each side of the piston, the temperature is kept very low by water-jacketing the cylinder and stuffing box and causing water to circulate through the piston itself. The working mixture is compressed by the main piston on its return stroke to about 12 atmospheres, and when at its dead point exploded by two electrical igniters, one placed close to the piston, and the other close to the inlet valve. On the side of the engine may be seen the gas and air pumps, which are relatively proportioned and connected together. The pumps are provided with piston valves which are operated by an eccentric on the main crank shaft, and serve to direct the gas and air first to one end and then to the other end of the cylinder, performing the same function that is fulfilled by the admission valve of a steam engine, the inlet valves on the ends of the cylinder being merely check valves to prevent back pressure from the cylinder into the pumps. The air and gas arrive, separated from each other, at the valve casing, where they are thoroughly mixed, and enter the cylinder. During about 40% of the stroke, the gas is caused to pass around a by-path, and none enters the working cylinder. During this 40% of the stroke, air alone is introduced in the cylinder, scouring out the products of combustion, which pass through the exhaust, it also forms a layer between the burnt gases and mixture, lowering the temperature inside the cylinder, and making pre-ignition impossible.

One of the most important features in Mr. Körting's engine, and one which he claims it would be impossible to operate without, is a projection in the combustion chamber, below the inlet valve. This projection is almost semi-circular and of a special form which is the result of considerable experimentation. It is on the concave side of the combustion chamber, which causes half of the moving charge to become deviated at right angles, to the rest of it, thus producing a whirling and rolling motion. This materially assists the scouring action of the air and assists also the thorough mixing of the air and gas, which mixture thus loses all tendency to force itself in the form of jets, into the dead mass of burnt charge and air ahead of it, which it would ordinarily mix with, and cause considerable loss of the new mixture, by its passing out through the exhaust. Were this effect not produced, the loss of gas escaping through the exhaust ports would be so great

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as to make the engine as built, uncommercial. The regulation of the engine is secured by the governor acting on the slide of a link motion, which acts on the distribution slide of the gas pump, and according to the position of the slide of the link, the rate of circulation in the gas pump is increased or decreased, controlling the quantity delivered at each stroke. The quality of the mixture remains the same. Mr. Ernst Körting informed the writer that this engine could be built with 25% less lbs. of material than any gas engine of the same H. P. in the market and at a manufacturing cost per lb. not exceeding other types.

The Oechelheuser Gas Engine.

This engine is one of a number of important types of gas engines of large power; which have developed since the sudden demand caused by the utilization of "high-furnace" gases for gas engine driving. This engine has but one complete cycle per revolution. As illustrated in Fig. 29 it has one long horizontal water-cooled cylinder, containing two pistons, which between them perform the functions of admission and compression of the charging mixtures and the discharge of the products of combustion or exhaust gases. The engine has no valves or cam-shafts. It will be noted that the front piston is connected to the center of a three-throw crank and the rear piston to the two outer cranks. These cranks are 180° apart. The cross-head of the back piston is also attached to the piston-rod of a double acting pump, which compresses the gas and air mixture on one side of its piston and air alone on the other side. As the two engine pistons approach in the cylinder, the mixture is compressed between them to a pressure of from 8 to 10 atmospheres and exploded electrically. The pistons are thus driven apart, each doing its work upon the main shaft. Before the completion of the full stroke the front piston uncovers the annular exhaust port, permitting the discharge of the exhaust gases. The rear piston at the end of its stroke uncovers first a port admitting air under slight pressure, to scour out the remaining products of combustion, and then a second port, through which the previously compressed explosive mixture from the pump is admitted. The exhaust port remains uncovered while the mixture pushes out the scavenging air, and then the pistons close all the ports on the return stroke. Compression then follows, and the cycle is repeated. It is claimed that none of the fresh charge

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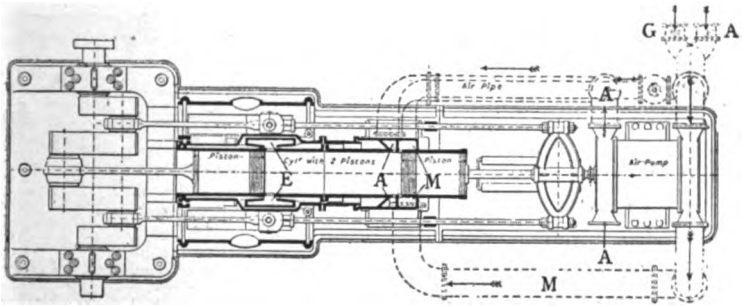
escapes through the exhaust, as the cylinder is so proportioned that even when running at maximum load the charge occupies but 70%. For slight variations in speed the governor controls the proportions of mixture of gas and air. For wider limits it regulates the quantity of charge through the mixing valve cock and the return slide valve. Part of the compressed charge passes into the suction pipe, and is then transferred to the other side of the pump, instead of to the motor cylinder, as usual. Admission and exhaust are effected in one stroke instead of two. The cylinder dimensions are smaller for the same power than in the four-cycle type of engine, as one stroke is obtained at each revolution, and as this is effected by two working pistons, acting on the same shaft, the power is said to be increased fourfold. The turning moment on the main



A.—Air. M.—Mixture air and gas. E.—Exhaust. G.—Gas. A.—Air.

FIG. 29.—600 H. P. Oechelheuser Gas Engine.
(Engines of 1,000 and 1,200 H. P. under construction.)

shaft is produced by a couple, and the unbalanced forces transmitted to the bed-plate are much less than ordinary. Great regularity is obtained by the impulse at each revolution, and rapid expansion follows each explosion. The engine is, however, of considerable length, and the extra cost and complication of the three cranks, three connecting-rods and two cross-heads, rods, pump and pump-gear are to be taken into consideration. In the latest designs the pump is placed below the floor and under the engine, making a very compact arrangement. The Kraft Gas Gesellschaft, of Berlin, which is now manufacturing this engine at Aschersleben, is turning out a large number of these engines, up to 2,000 B. H. P., in the twin arrangement, for driving electrical machinery, fans, air-compressors, etc.

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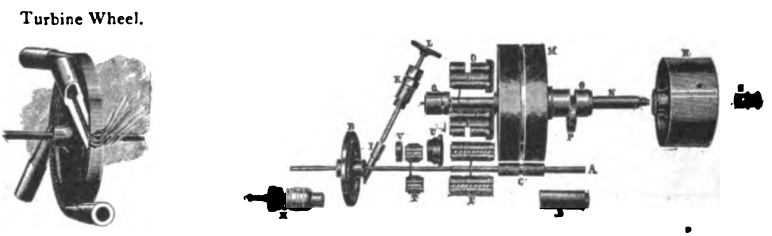
The Steam Turbine.

The very important work done in recent years upon the development of that oldest of steam engines, the steam turbine, bids fair to revolutionize steam engine practice, and although it is self-evident it does not possess the universal applicability of the ordinary steam engine, there is a very large field open for its application, and it is particularly well adapted to the needs of electrical engineers.

It is remarkably simple and compact, requires a minimum of attention and repairs, has no valves and no rubbing surfaces, except in the bearings, which in the forms employed show an insignificant wear, and the internal parts require no lubricant, consequently there is no danger of carrying grease into the boilers where they are fed by water condensation from surface condensers,



A.—Turbine Shaft. B.—Turbine Wheel. C.—Pinion. D.—Bearing of shaft end. F. G.—2 Part Bearings. H.—Thrust Bearing. I.—Feeding Nozzle. K. L.—Contro'ling valve. M.—Gear Wheel. N.—Motor Shaft. P.—Lubricating ring. Q.—Pulley. S.—Nut screw. T.—Exhaust valve.

Fig. 30.—Principal parts of the "de Laval" Steam Turbine.

and the absence of packing glands and internal rubbing surfaces permit of the use of steam of high degrees of superheat.

As there are no reciprocating parts and everything is so perfectly balanced the foundations are of but slight expense, it being only necessary to support so much dead weight. The turbine itself is comparatively light and economical in first cost and in operation, and will regulate within a very small percentage from no load to full load. In the ordinary steam engine live steam is admitted into the cylinder, which had been cooled but a moment before by its connection with the exhaust, the resulting condensation is not apparent in the steam turbine to any extent, owing to the gradual temperature changes and constant temperatures maintained at any given point.

In Fig. 30 is shown an illustration of the working parts of a de Laval turbine, such as has been extensively employed in

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Europe and to some extent in this country, and in Fig. 31 is illustrated a standard 300 H. P. unit connected to two dynamos of corresponding output; this is the largest turbine of this type which has thus far been built. As indicative of the high class of workmanship and care necessary in constructing this type of high speed steam engine, I would call attention to the large gear wheels lettered M which I was informed at the Humboldt Works at Kalk, Germany, each took 14 days to complete. I made particular inquiries of various turbine manufacturers regarding the amount of wear of the blades, and was invariably told it was inappreciable where superheated steam was used. The de Laval Co. exhibited a 300 H. P. turbine wheel at the recent Paris

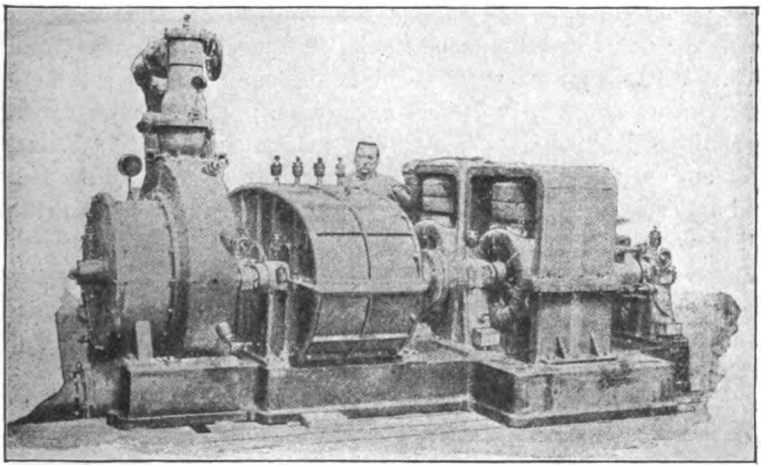

FIG. 31.—300 H. P. de Laval Turbine and Dynamos.

Exposition, in which the blades showed no apparent wear after having been in use for seven years. Prof. R. H. Thurston's recent test upon a de Laval turbine showed an increase in economy of one per cent. for each 3° Fahr. of superheat, and that with 37° of superheat the capacity of the turbine was doubled, due almost entirely, he claims, to the lessening of the skin friction.

In Fig. 30 is shown the turbine wheel B mounted upon the very slender shaft A, whose flexibility permits of its great deflection due to the forces set up by the turbine wheels running at such high speeds, and permits the wheel to revolve about its

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axis of gravity; to the left of Fig. 30 is shown a wheel with its four nozzles, one of which is cut away to show the expansion of the steam as the opening diverges; the form of the blades is also indicated.

In Fig. 32 is shown an illustration of one of the two steam turbines ordered by the City of Elberfeld, Germany, from the firm of C. A. Parsons, to whom I am indebted for this original photograph. It is direct-connected to a 1,000 K. W. three-phase generator. A recent test was made by Messrs. Weber, Lindlay and Schroeter to determine steam consumption under different loads with the following results: Average pressure 11 atmospheres, the steam was superheated 14.3° cent, dynamo load 1,190 K. W. (overload), 955 K. W. (full load), 745 K. W. ($\frac{3}{4}$ load), 499 K. W. ($\frac{1}{2}$ load), 247 K. W. ($\frac{1}{4}$ load); the number of pounds of steam consumed per K. W. was respectively 19.3, 20.1, 22.2, 25.4, and 33.8. When running without the field magnets excited, the engine consumed 2,604 lbs. of steam per hour; when running with no load but field magnets excited, the turbine consumed 4,057 lbs. of steam per hour, the variation in speed from no load to full load and vice versa was 3.6 per cent. with non-inductive load, the fall in voltage from no load to full load was 1.02 per cent. with inductive load under similar conditions 11 per cent. This is the largest steam turbine constructed abroad up to the present, 1,500 H. P., but is exceeded by the Parsons 3,000 H. P. turbine installed by the Westinghouse Co. recently in Hartford, Conn.

The Sulphur Dioxide Gas, or "$S O_2$" Engine.

In 1889, Mr. R. Behrend, an engineer of Hamburg, Germany, and Dr. Zimmerman, of Ludwigshafen, patented a system which they had invented for utilizing the heat units contained in exhaust steam, and their tests showed gains as high as 56 per cent. additional power secured, without the expenditure of one pound additional fuel. The system developed by them and used upon an experimental engine plant, was not brought to perfection, by reason, among other things, of their difficulty in securing proper acid pumps. The improvements in ice-making machinery have now supplied the requisite pump, and a large amount of valuable data and experience. The results which they secured, however, were so promising that they brought them to the attention of Prof. E. Josse, of the Kgl. Technische Hochschule of Charlottenburg, Germany, an authority on subjects of this char-

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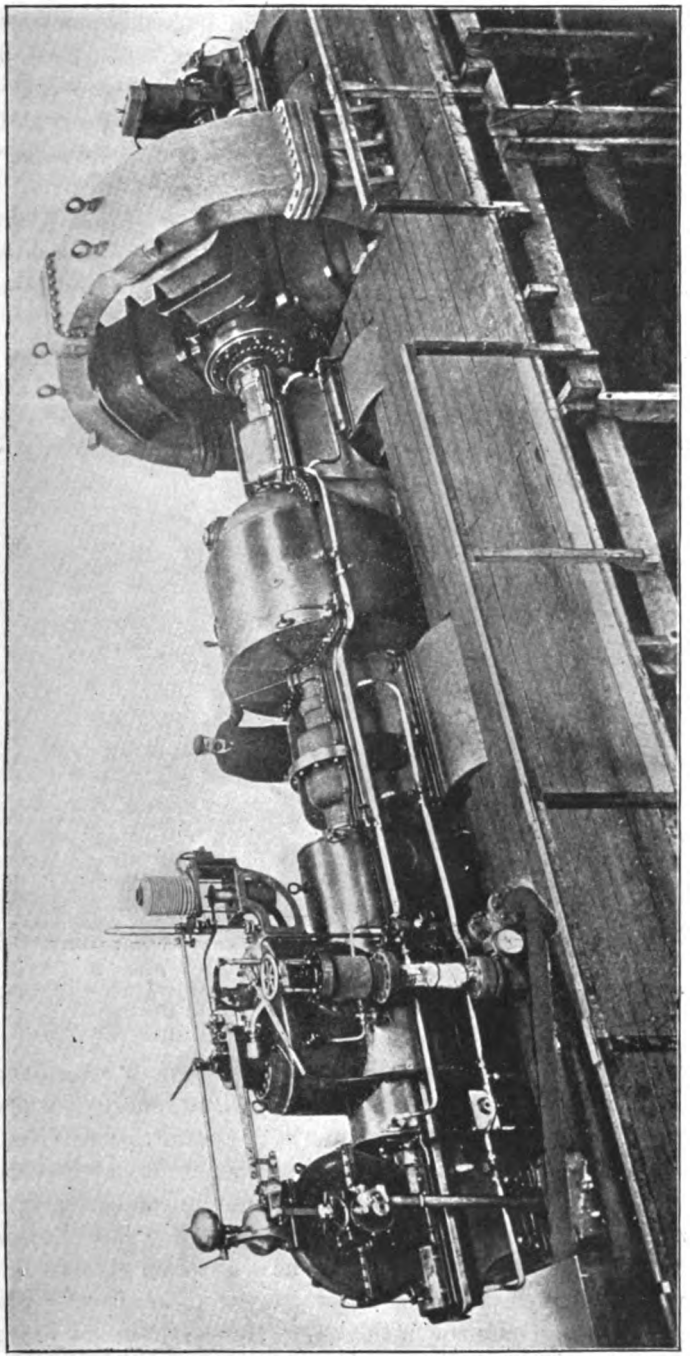

FIG. 32.—1000 K. W. Parsons Steam Turbine Outfit at Elberfeld, Germany. (1,500 to 2,000 H. P.)

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acter, and they requested him to examine into the practicability of their ideas, and eventually to make further tests. Prof. Josse following up the work of Messrs. Behrend and Zimmerman, secured results of the greatest interest and importance, and the work which he now has in hand at Charlottenburg, is being carried forward in the interests of the three largest electrical concerns in Berlin, *i. e.*, Siemens and Halske, The Union Elektricitäts Gesellschaft, and the Allgemeine Elektricitäts Gesellschaft.

The system which has been developed is quite simple, and is briefly as follows:

As is well known in steam engine practice, after steam has

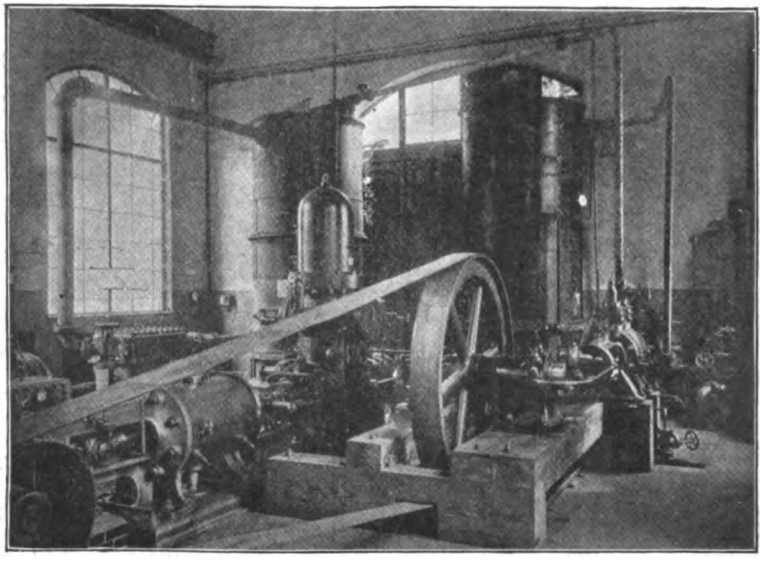

FIG. 38.—Sulphur Di-Oxide or "S O_2" Engine, in conjunction with compound Steam Engine. (The former is shown at the right.)

done its work in the cylinder or cylinders of a steam engine, there results a very considerable loss of heat energy; when the steam is discharged into the open air, or passed through the condenser. When exhausted in the open air, it has a temperature of about 212 deg. F., and in passing into a condenser it has a temperature of about 140 deg. to 160 deg. F., depending upon the amount of vacuum. The latent heat of steam given up in the changing from steam to hot water, has heretofore been wasted in the condensing water or in the air. Messrs. Behrend and Zim-

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merman, desiring to utilize this waste caloric, employ it to create a new supply of power by vaporizing a liquid having a boiling point considerably lower than that of water, and after extensive experiments, adopted sulphurous acid (H_2 S O_3), a substance which is readily and economically obtained. Ammonia, nitrogen and benzol might also be thus employed, but the sulphurous acid, possesses the advantage that it can work in a cylinder without lubrication, which is not the case with ammonia. The pressures corresponding to the available temperatures are also favorable to the employment of this liquid. The working apparatus is shown in the appended illustration (Fig. 33), which represents the first engine tested at the Technische Hochschule. To the left is seen

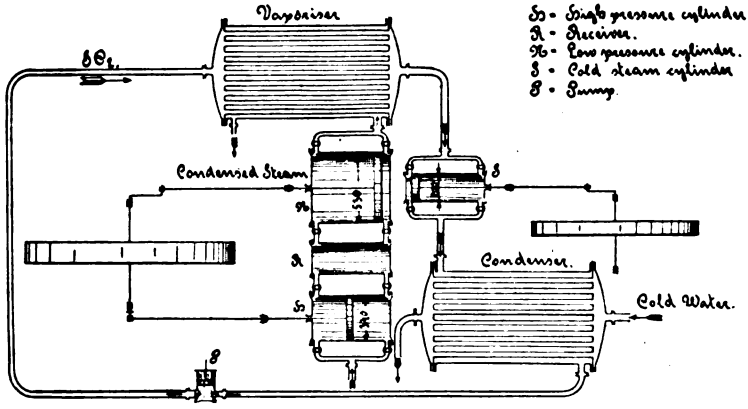

DIAGRAM SHOWING THE RELATIONS OF WORKING PARTS OF S. O_2 ENGINE.

FIG. 34.

the steam engine which has a pump for its load; behind it is the vaporizer; to the right, the S O_2 engine; and behind that the S O_2 condenser. This arrangement was designed by Prof. Josse. The principle and mechanical details are illustrated diagrammatically in Fig. 34. The dimensions given are in millimetres. The letters H and N represent the high and low pressures of an ordinary compound steam engine, with a stroke of 19.69 inches, and a speed of 41.5 revolutions per minute. From the low pressure cylinder end, exhaust steam passes into the surface condenser, or as it is termed, the "vaporizer." In this vaporizer or condenser, the sulphurous acid (H_2 S O_3) is utilized as the cooling medium instead of water. Possessing such a low boiling point, the heat of the exhaust steam liberates sulphur dioxide (S O_2) which, passing

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into a cylinder of the auxiliary engine s, does its work as if it were an ordinary steam engine. This auxiliary cylinder has a diameter of 11.81 inches, a stroke of 19.69 inches, and a speed of 77 revolutions per minute. After being utilized in this cylinder, the sulphurous vapor, passes through the tubes in the surface condenser (shown in the diagram), around which tubes cold water is flowing, which condenses the sulphurous vapor again into sulphurous acid, which is pumped by the pump P back into the vaporizer, where it begins its cycle again—the same acid being used over and over again without loss. The machine is thus, in fact, a closed-heat engine. In a long series of tests made with the compound engine shown in Fig. 18, the following results were attained. The engine which is of the compound type, of modern construction, developed with a steady load 34 indicated H. P., with a consumption of 18.96 pounds of steam per indicated H. P. hour. The auxiliary engine working with the sulphurous vapor indicated 19 H. P. That is an increase of 56 per cent., and yielding, instead of one H. P., 1.56 H. P. for the same steam consumption, and reducing the steam consumption from 18.96 to 12.13 pounds per indicated H. P. The experiments show on the average that for every 15 kilograms or 33.169 pounds of steam passing through the main engine, one H. P. could be gained in the auxiliary cylinder. Applied to an ordinary single-cylinder steam engine, exhausting directly into the air at a high temperature, the percentage of power saved by this new system, would be much higher than the economy reached in these experiments, which are made with an improved compound engine. It is claimed from these experiments that given a fairly economical compound engine using 16.5 pounds of steam per indicated H. P. hour, that half an indicated H. P. could be produced in the auxiliary machine for each indicated H. P. developed in the main engine, assuming an average vacuum of 23.62 inches, corresponding to a temperature of 140° F. The saving of heat must be accomplished by using a liquid which can be vaporized at or below that temperature, and produce a high pressure. Assuming the upper and lower limits of temperature, within which the operation is confined, to be 140° and 67° F., the pressure of the sulphurous vapor would range from 10.05 to 2.35 atmospheres above open air pressure A working pressure as high as ordinary steam boiler pressure, is therefore readily obtained at a comparatively moderate temperature. The volume of sulphurous acid vapor, necessary to contain

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the number of heat units, corresponding to the work to be performed, is much smaller than the volume of steam, which would be required for the same purpose. As the saving to be effected by the customary engine, depends directly upon the difference between the highest and lowest temperatures involved, the greater gain will therefore be made, either when the water in the surface condenser is as cold as possible, or when the heat of the exhaust steam from the engine is at a maximum, as is the case with a single-cylinder steam engine without condenser, which may be anywhere up to 212° F.

Sulphur dioxide gas or vapor is of a somewhat viscous character and lubricates the working surfaces of the machinery, and without producing corrosion. There is thus a considerable saving of lubricants. The expense of this improvement is practically covered in the cost of the auxiliary engine or extra cylinder attached to an ordinary engine, and the vaporizer, condenser, piping and pumps. It is claimed that a 2,000 H. P. central station engine would furnish power to drive an additional 1,000 H. P. $S O_2$ engine, which can be connected as an extra cylinder to the steam engine, or run independently, and thus increase about 50 per cent. the power developed without adding a pound to the quantity of fuel consumed. Prof. Josse states that in mining and iron works districts, there are a large number of engines, which are condensing and non-condensing, which consume more than 10 kg. of steam, and in such cases 2,000 H. P. would be gained in a plant of 3,000 H. P. by the use of the cold vapor engine.

A triple expansion steam engine, to which an $S O_2$ gas engine has been attached, is being used for supplying light and power to the technical high school in Charlottenburg. Exhaustive tests have been made, and are being made on this engine by Prof. Josse and his assistants. Through the courtesy of Prof. Josse and Mr. Louis Magee, Director of the Union Electric Co. of Berlin, I was enabled to secure the data here presented, and had the pleasure of seeing, recently, this engine running and undergoing test. Prof. Josse, to whom I am indebted for a beautiful photograph of this new engine which I regret to say I am unable to show you tonight on account of patents pending; informed me that even with the triple expansion the $S O_2$ engine gave an increase of H. P. of 35 per cent. with practically no increase in the operating expenses. I had hoped to present the latest results secured by this new engine, but they did not arrive

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in time to embody them in this paper. Prof. Josse informed me that he believed it was inadvisable to go higher than double expansion, and that the preferable method of construction was to place the cylinder of the S O_2 engine in tandem with the steam cylinders. On my asking if there was any danger in moisture getting into the system, thus forming sulphuric acid, which would attack the surface of the cylinder, etc., he said this was impossible. This development in engineering practice is certainly a most interesting and promising one, and it is of interest to note that the Allgemeine Elektricitäts Gesellschaft is now installing an S O_2 engine in its Markgrafenstrasse station in Berlin. The system is not without its disadvantages, and even possible danger. Everyone knows the discomfort produced in a room where a common sulphur match is ignited, and in all types of engines there is always a possibility of a leak occurring. A comparatively small amount of sulphur dioxide gas produces a large amount of discomfort, and a large amount of it may incapacitate those working about the machinery, and if exposed thereto for a considerable length of time may even result in death. There are also the well-known corrosive effects produced. These are not cited with a view of disparaging this most interesting development, but would rather serve to indicate that for such a system to be most successful, the S O_2 engine should be operated as an independent engine, and so boxed in and ventilated as to reduce to a minimum the disadvantages resulting from possible leakage. The care of this engine is exceedingly simple, as no lubricant is necessary, and as for the existing steam engine absolutely nothing need be changed. In the methods of construction, very great care is taken to reduce the chances of leakage to a minimum. Great care is taken in the packing of the stuffing boxes, and in addition an extra stuffing box is placed on the cylinder, and connected to the condenser, so that although the pressure inside of the cylinder is 14 atmospheres, there is a pressure of but from one to one and a half atmospheres at the outer stuffing box. Prof. Josse says the engine can be made absolutely scentless, and that no difficulty need be experienced on this score. He also says the results of his tests far exceeded the original calculated and estimated results, and completely justify the practical application of the Behrend system for the improvement in steam engines.

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A Trolley Omnibus.

In Fig. 35 is shown an illustration of the overhead double trolley circuit used to operate the electrical omnibus in the Vincennes Annex of the Paris Exhibition. The omnibus was

Fig. 35.—Double Trolley Line for Electric Omnibus at Vincennes, Paris.

flexibly connected with a traveling trolley or contact carriage, which was driven by an electric motor and which traveled along on the two overhead wires. The current supplied to the motor on the omnibus was a direct current, and connections were made

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therewith, so as to supply a three-phase current to the motor driving the trolley-carrier so that it tended to travel slightly faster thereby always keeping the supply cable taut. The trolley wires were suspended first on one side of the road, then on the other and at times in the center, and the omnibus itself wended its way in and out of the numerous vehicles on the road with perfect facility. It would seem that there are various places where such a trolley automobile could be applied with advantage.

The Electric Plough.

During my stay in Berlin, through the courtesy of Director Louis Magee of the Union Electric Co., I was shown an improved form of electric plough at work in the suburbs of

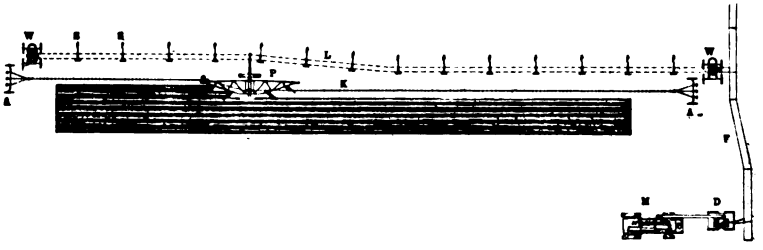

Fig. 36.—Diagram of Electric Ploughing System.

Berlin. The illustrations in Figs 36 and 37 will serve to indicate the system employed. Direct current at 500 volts was supplied from the neighboring station of the Berlin Electricity Works, and the plough itself was equipped with three ploughshares at each end, and was estimated to do the work of 15 horses. The illustrations serve to indicate quite clearly how in this system the line wire was connected to the traveling reels and to the trolley lines, and shows how this line is moved sideways across the field as the plough progresses. The feeding chain and anchors are shown, and the method of tipping up the plough body in starting a new furrow on the return trip. I found it necessary to walk quite rapidly to keep up with the plough, which was simultaneously cutting three deep furrows in soft loam in a very impressive manner.

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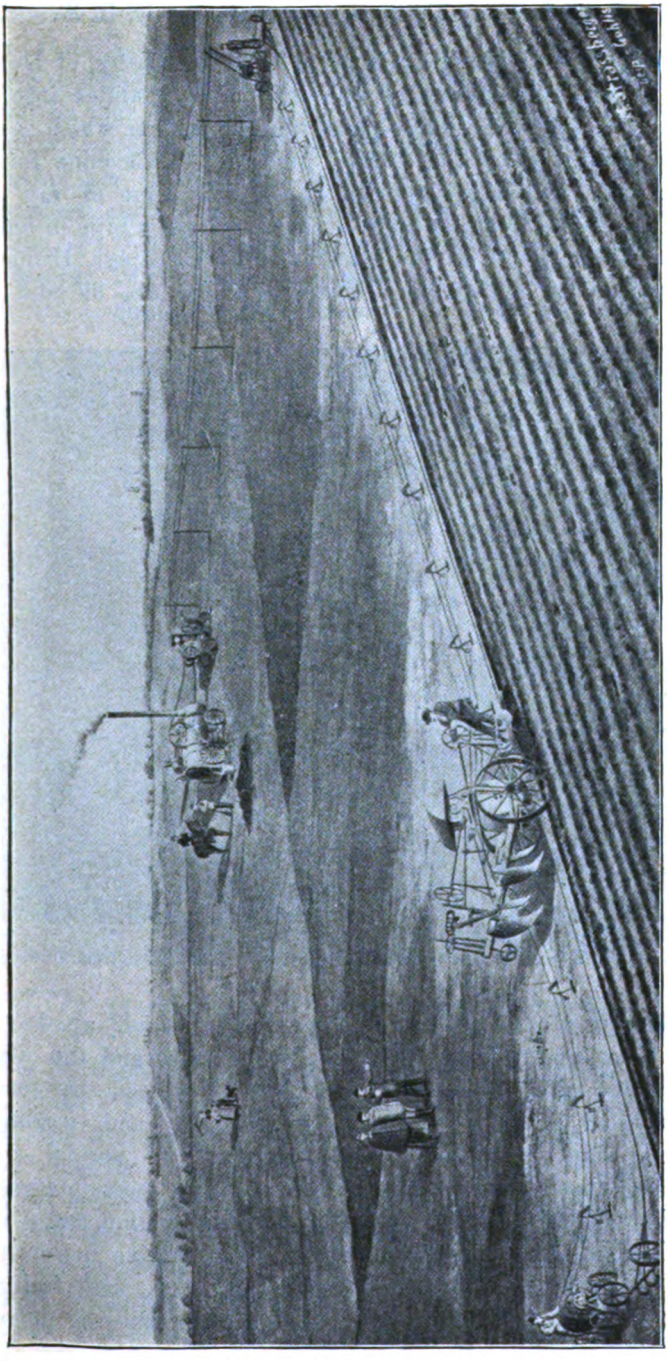

FIG. 37.—The Electric Ploughing System in Operation.

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Ganz & Co.'s High-Tension Three-Phase R. R. System.

Through the courtesy of Director Otto F. Blathy, of Messrs. Ganz & Co., of Budapest, I was enabled to examine into the company's high-tension three-phase railroad system, which is now being installed upon the Lecco, Sondrio & Chiavenna line in North Italy, and which system was at the time of my visit being run experimentally upon a circular track a mile in length at Alte-Ofen Island, in the Danube, near Budapest, Hungary, illustrations of which are shown in Figs. 38, 39 and 40.

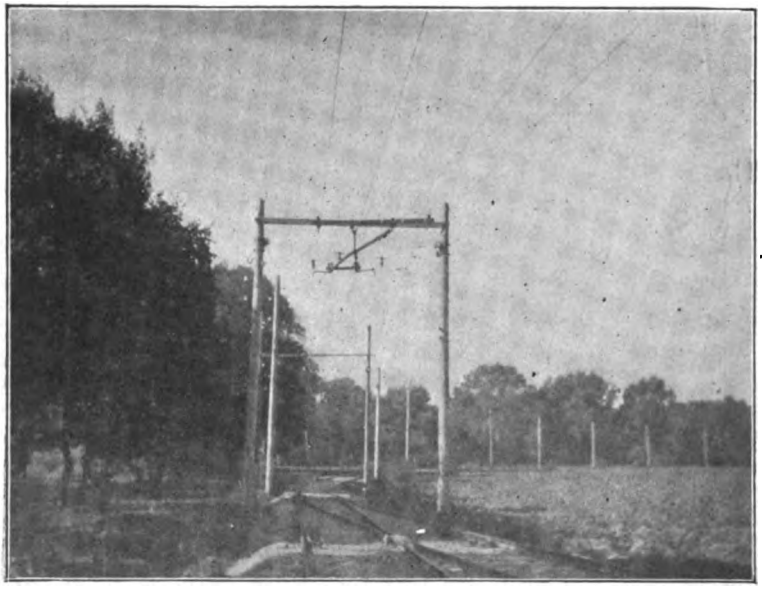

Fig. 38.—Ganz & Co.'s Experimental 3-Phase R. R. at Alte-Ofen, Budapest.

The length of the Italian electric road, which up to the present has been operated by steam, is 66 miles and the maximum grade 22%. It is safe to say that this road, by reason of its great length, problems in freight and passenger haulage, high potential employed, and its special electrical and mechanical features, represents the most interesting electrical railway installation now under construction, and it will be followed with the greatest interest. The motive power now being arranged for represents about 7,400 H. P., with facilities for increasing when necessary. The power will be derived

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from a waterfall near Morbegno, 9½ miles from Calico and 15½ miles from Sondrio. Four 2,000 H. P. Shuckert three-phase dynamos generating 20,000 volts at 15 cycles are direct-connected to four turbines, which are supplied from a raceway between two and three miles long, delivering 35 cubic meters of water per second and having a fall of 30 metres. The three-phase current of 20,000 volts will be supplied direct to the line, and the 12 sub-stations will transform it to 3,000 volts and supply 12 independent sections of the railway line, each of which is equipped with fuses. Two over-head trolley wires

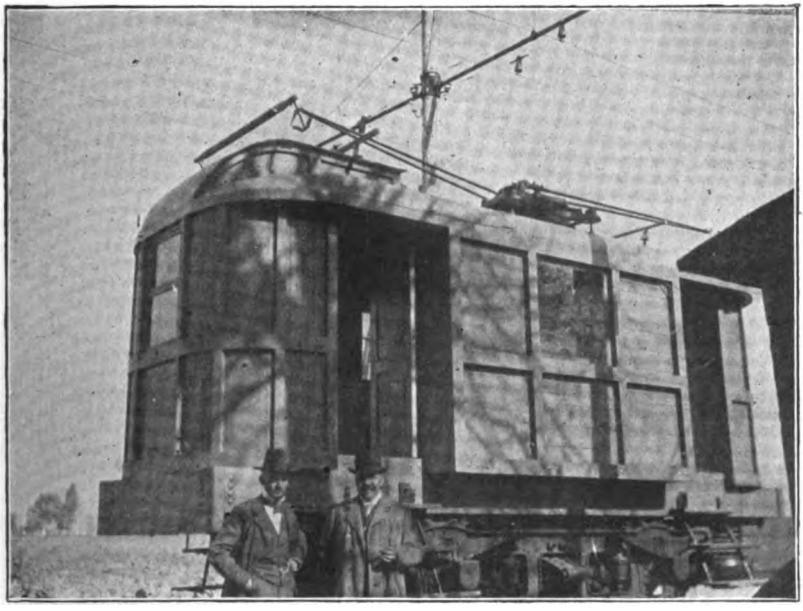

FIG. 39.—Ganz & Co.'s Electric Locomotive at Alte-Ofen.

8 mm. in diameter represent two of the phases and the track the third. The line insulators are of porcelain, having five petticoats decreasing in size from top to bottom. The line wire, which is of copper, is 7 mm. in diameter. The sections of road are operated upon an ingenious block system; when the stop-signal is set, the line circuit is opened and simultaneously the powerful brakes on the train are set. Passenger and freight traffic are operated independently. The freight locomotives will be of 700 H. P., employing four motors, and capable

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of hauling 250 tons at a speed of 19 miles an hour up a 10% grade. The passenger locomotives are also equipped with four motors, each weighing about 3½ tons and representing 300 H. P. The schedule speed is about 37½ miles an hour on the level and about half that on grades. The 3,000-volt current is taken from the trolley lines by two copper rollers 16″ long and having a diameter of 3½″. These rollers, which are mounted in the same axial line, revolve upon steel ball bearings (through which no current, however, passes) and are separated by 5″ of hard wood saturated in paraffine under pressure. On the left and right

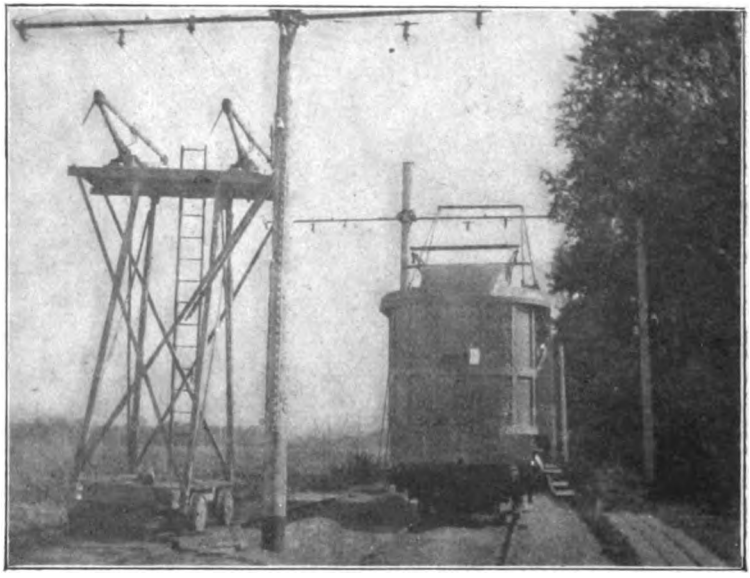

FIG. 40.—Showing details of Alte-Ofen Line, Budapest.

sides of this pair of rollers are copper cones about 8″ long, rigidly connected to the trolley-support. The base of the trolley is mounted on a long horizontal hinge on the top of the car and connected to a piston of an air-cylinder, so that the trolley can be raised and lowered by air-pressure. Each of the "primary" or high-tension motors has its trolley with double rollers. Collecting-brushes running on graphite collars take the current from the two rollers, being held against them by spiral springs. The current is then led by highly-insulated wires, protected by grounded metallic tubing, to the motors.

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Each car is mounted on two four-wheel trucks, one of which is illustrated in Fig. 41, and is equipped with two "primary" and two "secondary" induction motors, or four in all, each of 150 H. P. Each rotor weighs about 1½ tons. The air-gap is between 4 and 5 mm. The 3,000-volt current passes directly to the stationary windings of the "primary" motors. In starting up the train or in climbing a grade the motors are connected in "cascade"—that is, the windings of the "primary" rotors, which are designed for 300 volts, are connected to the stationary windings of the "secondary" motors, while their rotors are connected to the fluid resistances; this gives a speed of about 18½ miles per hour. When speed is attained the controller-handle

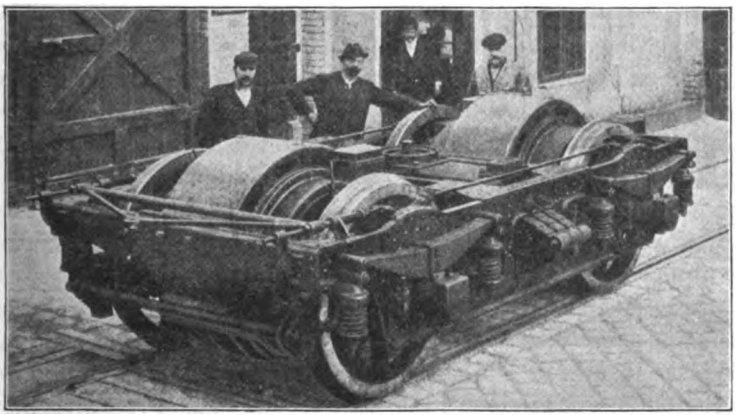

FIG. 41.—Ganz & Co.'s Electric Locomotive Truck, with Two Three-phaze Motors, for Italian Railroad.

(which has only two positions, "half-speed" and "full-speed") is thrown to its second point, which throws the stationary fields of the "primary" motors on the line, and their rotors on the fluid resistances which are slowly cut out of circuit, the secondary motors meantime being thrown out of circuit. This arrangement gives a speed of 37½ miles per hour. The wires in both field and rotor windings are invisible as they pass longitudinally through insulated tubes in the iron, and at the ends of the windings are insulated by mica and protected by plates or caps bolted on. The controllers at each end of the car are connected mechanically, and the high-tension switches are connected electrically. A small transformer on the locomotive connected

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to the line delivers current at 100 volts to a three-phase motor for compressing air for use on the air-brakes, operating the high tension switch, raising and lowering the fluid in the resistance boxes (which is simpler than raising the plates), and for raising and lowering the trolley. The same transformer supplies current for lighting the train; Cruto three-phase incandescent lamps are employed, the periodicity being but 15 per second, the fluctuations were too noticeable in the ordinary lamps, so the Cruto 3-filament lamp was employed and showed no fluctuation.

The three-phase liquid rheostat is a feature of considerable interest. It consists of an iron box having three wings to it. From the top of the box depend three separate cylinders. Supported inside of each cylinder are two sets of iron plates. They are of varying length, and are rounded at the lower extremity. The alternate plates are connected in pairs, the current entering by one pair and leaving by the other, the sets being attached to the three phases of the low-tension rotor circuits, which have a potential of 300 volts. The lower portion of the outer case contains a solution of sodium carbonate. The upper portion of this outer case is supplied with compressed air, which, according to the rate with which it is allowed to pass into the outer chamber, causes the liquid to rise in the three cylinders. The liquid as it rises, comes in contact with the various iron plates, one after the other, and more or less resistance is thus cut of circuit, depending upon the height of the solution. By releasing the air pressure in the outer compartment, the solution immediately drops into the lower part of the case, and the plates are then entirely separated from each other. The entire height through which the solution passes is less than 12 inches. This resistance box, which is the result of a large amount of experimentation, enables the motor-driving torque to be kept constant during acceleration. The air exhaust valve is a lift type of valve, normally kept open by a spiral spring. The valve for operating the rheostat is compound, having several ways through it. On being operated, the latter first opens a clear way for the compressed air to a cylinder, and to the top of a piston which compresses the spiral spring above referred to, and closes the exhaust valve. The air is next admitted slowly through a small throttling aperture, which admits the air at low pressure, to the outside of the resistance box casing. When half-speed has been attained, the motion of the controller lever when thrown to full speed, causes

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the air cock to close the throttling aperture, and open another, thus relieving the air above the upper surface of the exhaust valve piston, permitting the compression spring on this valve to instantly open it, thus throwing in again instantly the whole resistance. These operations are repeated in securing acceleration from half to full speed, and in securing retardation from full to half speed, at which time the motors are in "cascade," as described.

The motors are direct-connected to the axle; that is, there is no gearing; the rotor axle is hollow, with an internal diameter of 8″ and is lined with brass, permitting the car axle, which has a diameter of 4″, to pass through it. The circuits to the three collector-rings pass through grooves in the rotor shaft. The rotor shaft and the car wheels are flexibly connected, and thus jarring and vibration are prevented. The rotor has at one end the three collector-rings, upon which rest the three carbon block brushes. At the other end of the rotor is a driving-flange, which is connected to the driving-wheel on that side through two links, one of which acts by thrust and the other by tension, the two stresses being of equal magnitude.

In the experimental plant at Alte-Ofen, Budapest, a potential of 3,000 volts was supplied from a neighboring plant and the locomotive shown in Figs. 39 and 40, had but two motors upon it. The photos and lantern slides will serve to indicate the character of the car, track, trolley lines, methods of insulation, etc. I am indebted to Dr. Otto F. Blathy and Mr. Windisch Antal of Messrs. Ganz & Co., and to Mr. Francis Jehl, for assistance in preparing this data and for my trips over the road.

Siemens & Halske High Tension Three-Phase R. R.

The firms of Siemens & Halske, Allgemeine Elektricitats Gesellschaft, and Borsig & Co., of Berlin, have formed an organization for the study of problems connected with the operation of electric railways under steam conditions. The work I shall refer to here has been prosecuted by the first mentioned firm, which has for a considerable period given this subject attention. I am indebted to the company's engineers, particularly to Mr. Walter Reichel, the Chief Engineer of Messrs. Siemens & Halske, for the data here presented. Mr. Michael Dolivo-Dobrowolsky, Chief Engineer of the Allgemeine Co., informed

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the author that his company is also constructing a locomotive for experimental test, and Borsig & Co., the well-known engine builders, are co-operating with the other concerns in this important undertaking. Messrs. Siemens & Halske had made some interesting experiments with three-phase current in the year 1892 at the Werner Works, Charlottenburg, upon a track 360 metres long, and in the year 1897 decided to build a special experimental line for testing an electrical equipment

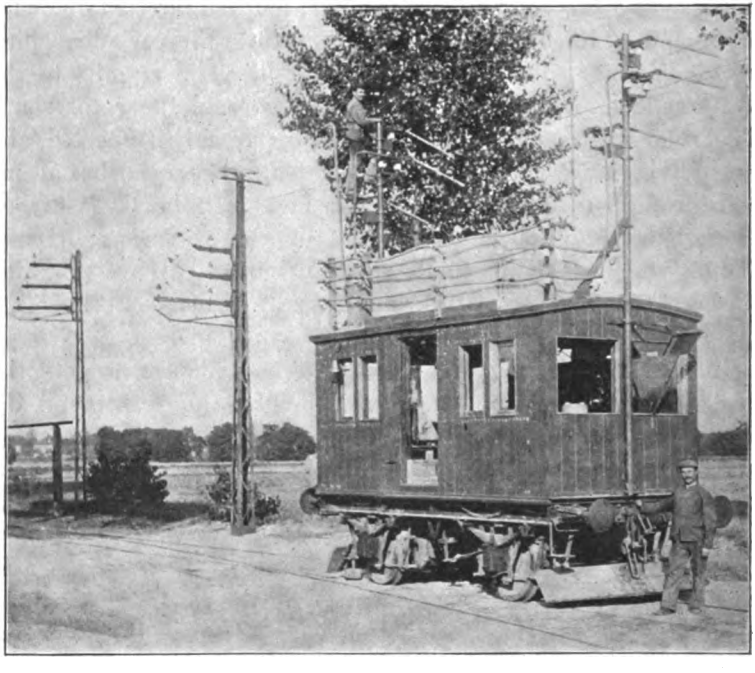

FIG. 43.—Original Arrangement of S. & H. Three-Phase R. R. near Berlin.

employing three-phase alternating current motors, and an E. M. F. of 10,000 volts, and for testing various types of trolleys, circuit safeguards, crossing constructions, etc. The line was built from Grosse Lichterfelde to Zeblendorf over the Teltow road, and was undertaken in the spring of 1898, the track being laid for 1.8 km., standard gauge, with the power station at about the center of the line. The more recent tests referred to here, were conducted in the spring and fall of 1899, and the final tests in the spring of 1900.

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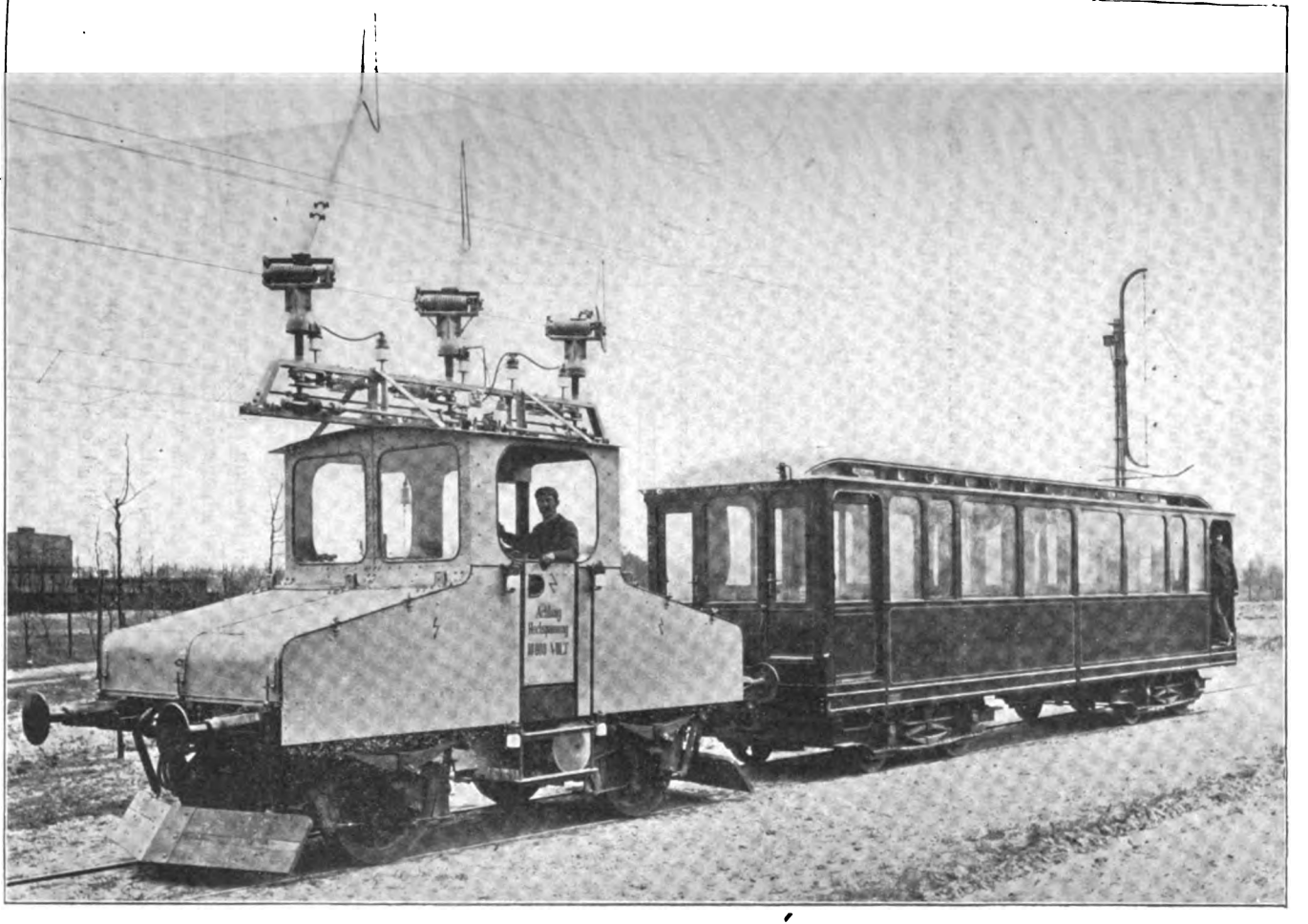

FIG. 43.—Latest Equipment Siemens & Halske Experimental Three-phase R. R. near Berlin, Germany.

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In Fig. 42 is shown the trolley line as originally arranged with the protective net below the conductors, and in Fig. 43 is shown the improved method of supporting the trolley wires and protective net. In the first arrangement the current was taken off by sliding contacts on the top of the wires, as shown in Figs. 36 and 38, and subsequently by side rubbing or sliding contacts. It was feared that at the high rates of speed desired, the ordinary forms of trolley wheels, loops and rollers, would tend to leave the wire. All three of the trolley wires, which are of hard drawn copper wire 8 mm. diameter, were placed at the side of the road, in order to get rid of the effect produced upon the telephone system by using the track for one-phase. The wires were

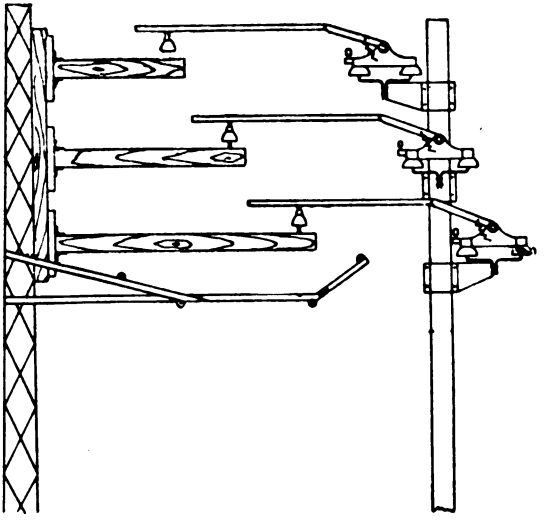

FIG. 44.—Original Arrangement of Trolleys.

held by porcelain bell insulators, tested for ½ hour under water at 1,500 volts, and lay at an inclined plane, and were screwed to wooden arms pivoted to the iron poles, permitting the wires to be strung and maintained separately and evenly, both winter and summer. Tension is kept on the wires by heavy weights placed inside the lattice poles at definite intervals, which act through a loose pulley and a block with six pulleys, and give a strain of 1,500 kg. on the wires. All the supports are lattice poles 40 metres apart, the ones carrying the weights being heavier and set in cement. As a precaution all the poles are separately connected

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to the rails by a copper wire 8 mm. diameter. Fig. 44 indicates the method of taking the current from the trolley wire. The trolleys consisted of strong aluminium pieces, pivoted about a horizontal axis, and fastened to an iron pipe, the contact parts swinging in a perpendicular plane to the working wires, against which they are held by a spring. In the system later employed, all three conductors lie in a vertical plane one metre apart. Curved iron supports are attached to the lattice poles. At the ends of these supports are tension devices, and the insulator supports are fastened at a slight angle. The three-part porcelain bell insulators are fastened to the support by means of a hempen rope; there is double insulation top and bottom. Sections of the conductor can move sideways, and yield to pressure as in the case of the ordinary under-running trolley. Metallic supports for the trolley wires tightly embrace the neck of the porcelain insulators, by means of pressure screws and spring rings. In Figs. 43 and 45 three bow trolleys are shown on top of the locomotive. Each is pivoted upon perpendicular axles, all of the same height, and which are insulated by strong hard rubber insulators. The loops or bows are of different lengths and inclinations. They also pivot horizontally to pass below crossings, etc., and are controlled simultaneously by a worm gear, operated from inside the cab. The working conductors and trolleys were tested with a current as high as 30,000 volts. Power is supplied from the sub-station of the Grosse-Lichterfelde Railway, which has a storage battery and direct-current motors for driving a rotary current dynamo. The latter is 12-pole, giving normally 700 v. and 50 periods, and 120 to 250 amperes at 500 revolutions per minute. This machine can be completely altered so that potentials from 385 to 4000 volts can be developed. There is also a rotary current transformer, with a transforming relation of $\frac{750}{10{,}000}$ v. with $\frac{157}{11.5}$ A. normal. With this plan it was possible to secure 750 v. directly, 2,000 v. directly, and 10,000 v. by transformation. The transformer dynamo frame and instrument cases were all grounded as a precaution. As first operated, the transformer stepping down from 10,000 to 750 volts was drawn along on a separate attached car with trolleys, in order to better observe the sliding contacts, and to be free from the high tension at the motor, which has no iron casing. There was also only enough room in the locomotive for the large resistances and other apparatus.

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Later an iron top casing was put on the locomotive, in which the transformer was placed—the equipment having the appearance as shown in Fig. 45. The metal parts of the locomotive are grounded to protect against the difference in potential. The

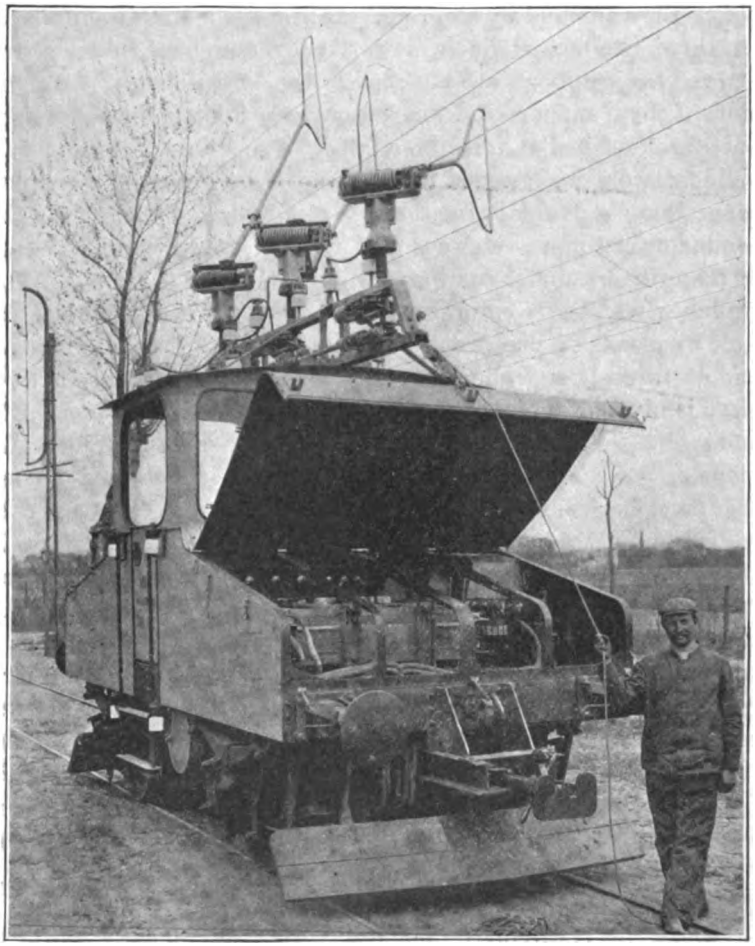

FIG. 45.—Siemens & Halske Three-phase Locomotive with Cover Raised, Showing Transformers, etc.

weight of the locomotive complete, was 16,000 kg. It is equipped with two rotary current motors, one on each of the two axles, and operating at 650 to 850 volts and 30 H. P. normal. The current is taken direct to the stationary windings. The rotor is

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provided with slip rings and ventilation. The air gap is 1.5 mm. Tested, these motors show an efficiency of 88.5 per cent., and the highest type is of 120 H. P. with 650 V., which is increased to 200 H. P. at 850 volts. The motors are flexibly suspended, similar to the street railway motors, and can turn upon the axles. Two pair of gear wheels serve to change the speed, with a gear of 1 : 4.65 for a speed of 40 km and 1 : 3.15 for a speed of 60 km. For the operations of 750, 2,000 and 10,000 volts, the same motors, frames, and rotary parts were used—only the stationary parts being exchanged for the direct operation with 2,000 volts.

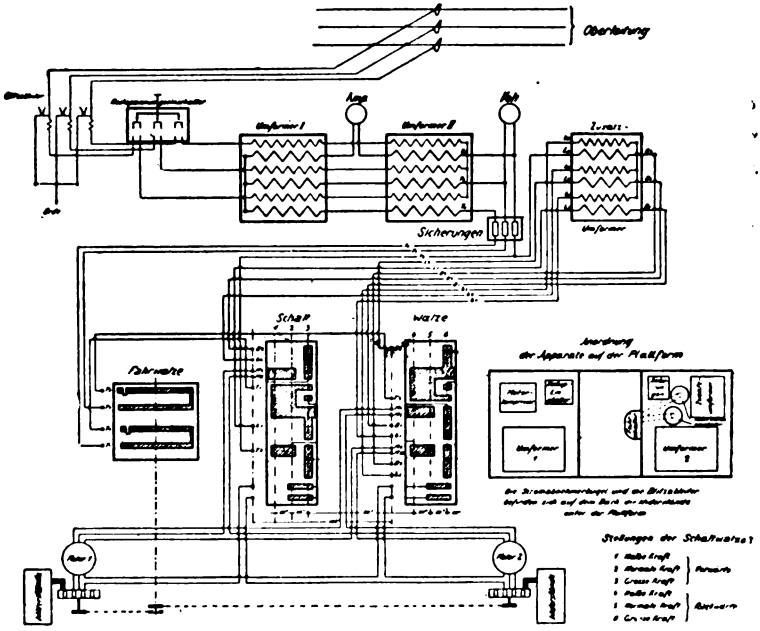

FIG. 46.—Diagram of Circuits.

Referring to the circuit diagram, Fig. 46 a controller constructed for 750 volts is employed for the switching in and out, and for the starting of the motors. The same has in its interior a reverser drum for changing the running direction, and a controller drum for switching the stationary windings of the motor in and out. The controller drum is mechanically connected by a chain gear with the starting devices for the rotating parts of the motors. When running with 750 volts, the controller is directly connected

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with the trolleys. When running with 10,000 volts, it is however connected through the transformer, from 10,000 volts to 750 volts, and a switch for 10,000 volts. Running with 2,000 volts the supply conductors to the primary parts of the motor can be cut off from the controller, and the car operated by two auxiliary switches, and without the use of the transformer. The reverser drum of the controller is so arranged that when employing an additional transformer (for instance with 10,000 volts) different currents can be taken off, thus obtaining the higher torque when starting through a higher E. M. F. (850 volts) than during the normal running (650 volts). The reverser drum finally has steps at which only two phases are connected up, it being thus possible to reduce the running speed by half. The starting devices are completely separated from one another to facilitate the cutting out of each motor, and to avoid any irregularities in the synchronism of the motors, with wheels whose diameters did not correspond. The controller is placed in the center of the locomotive. The high tension switch is outside at the end where one transformer is placed, and the starting devices are in the corresponding space which the other transformer occupies. The high tension switch is provided with a tube spark extinguisher, and the controller with a magnetic blow-out and a successive cut-out for the different phases. Connections between the controller, starting resistances and motors are carefully insulated to stand 4,000 volts, and are mechanically protected by rubber tubes, 6 mm. thick. Connections between trolleys and transformers are protected by one pipe. Ordinary packed resistances are employed, suspended beneath the car floor, near the starting devices, and properly protected. Safety fuses are on each side of the three low tension circuits, the high tension circuits being protected at the power house. Siemens horned (non-inductive) lightning arresters are used on the locomotive for each phase. Hand and air brakes are employed, and the usual volt and ampere meters. A locomotive with a load of 30 tons was run up to a speed of 60 km in 60 seconds time, with 700 v and 190 A. The locomotive alone, attained the same speed in 30 seconds. When run with a load of 30 tons at 60 km per hour, the motor consumed 70 A. at 700 volts. As is known, the starting torque varies with the square of the voltage; therefore, by increasing from 670 to 950 volts, the starting torque can be increased to double that at the normal tension. This can easily be obtained when employing transformers

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(in the operation with 10,000 v) by the addition of coil sections. The speed may be regulated by wheel resistances in the secondary, by opening a secondary circuit, or by "cascade" coupling. The first method causes a loss of current; in the second the motor has a somewhat lesser maximum torque—lesser efficiency, and a smaller output corresponding to half the number of revolutions; it is, however, preferable to resistance regulation. The same may be said of the "cascade" coupling, in which the torque is reduced to half of the output = to $\frac{1}{4}$. A braking action of the motors was obtained by decreasing the number of alternations of the dynamo through an increase of the field of the driving motors; likewise current was sent back to the accumulator battery, when going down hill.

The "Jungfrau" Three-Phase Railway.

The Jungfrau Railroad which has been under construction since 1897, and which, it is estimated, cannot be completed before 1908 to 1910, has attracted the attention of engineers the world over. It employs three-phase current of 7,000 volts, supplied by generators, operated by water power. Portions of the current are transformed to 120 volts, for the lighting of Lauterbrunnen and Wegern, and at stations, and for tunnel boring. The current for operating the locomotive is transformed to 500 volts. Two overhead contact wires are employed, the rails being used as the third conductor; the trolley wires are 16″ apart, and have double insulation between each other and between each wire and ground. These insulators come from America and were supplied by A. & J. M. Anderson of Boston, Mass. The supports are about 100 feet apart. Double trolleys with both slide and wheel contact makers are employed, as shown in Figs. 41 and 42.

The overhead conductors are bare, and supported on triple-petticoat porcelain insulators, mounted on wooden posts. A ten per cent. loss is allowed on the conductors. Lightning protectors are of the Siemens & Halske horned type, at each end of the circuits, and on every pole is a pointed wire connected to the earth.

The electrical generators are supplied by the Oerlikon Company, which also supplied the transformers and appurtenances, at present consisting of two units of 500 H. P., and one of 800 H. P., direct coupled to Gerard turbines, made by Reiter & Co. of Zurich, and having horizontal shafts with two wheels

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running at 380 revolutions. These generators are of the inductor type with stationary windings, and generate a three-phase current of 38 cycles and 7,000 volts, running at a speed of 380 revolutions per minute. They are connected to the turbines by flexible insulating couplings and are mounted upon porcelain insulators. Two exciters of 25 H. P. each at 600 revolutions, supply a direct current of 120 volts for exciting the fields. These exciters are shunt wound, and direct coupled to separate turbines. Each exciter is capable of exciting all four generators

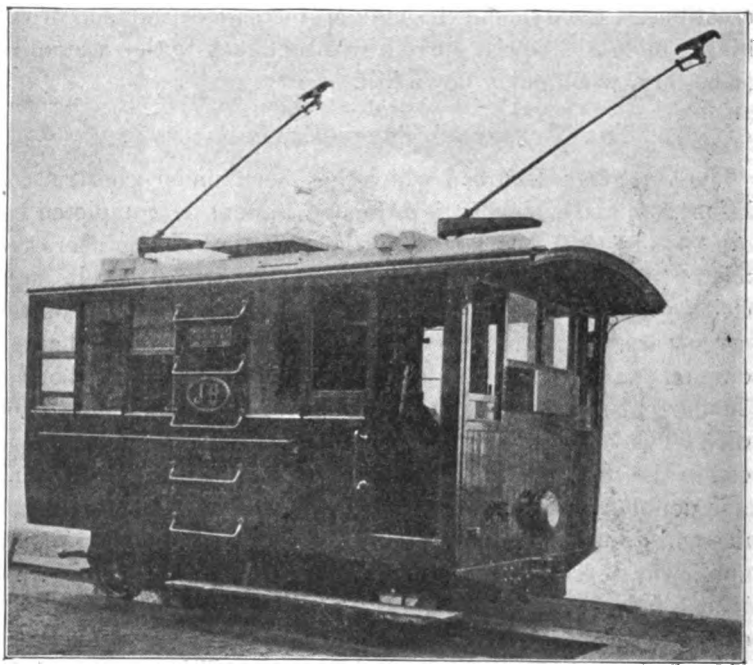

FIG. 47.—"Jungfrau" 3-Phase R. R. Locomotive.

which will constitute the plant. All of the turbines are automatically regulated. The present station at Lauterbrunnen will supply 2,000 H. P. from the "Weisse" Lutschine, and that at Grindelwald will supply, when completed, 3,000 H. P. This supply comes from the "Schwartze" Lutschine which gives 9,000 available H. P. The total length of the transmission line from the Lauter-brunnen Station to the top of the mountain is about twenty miles. At ten per cent. drop, the allowance would be about

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700 volts. The conductors are about 5/16″ diameter, and when the road is completed, there will be twelve substations along the entire line, about one and a half miles apart,—the highest being about 13,000 feet above the sea. There will be about seven miles of tunnel on this road—alone costing $1,000,000. The trolley wires in the tunnel are supported by iron hooks projecting from the rocks. Owing to the nature of the rocks it has not

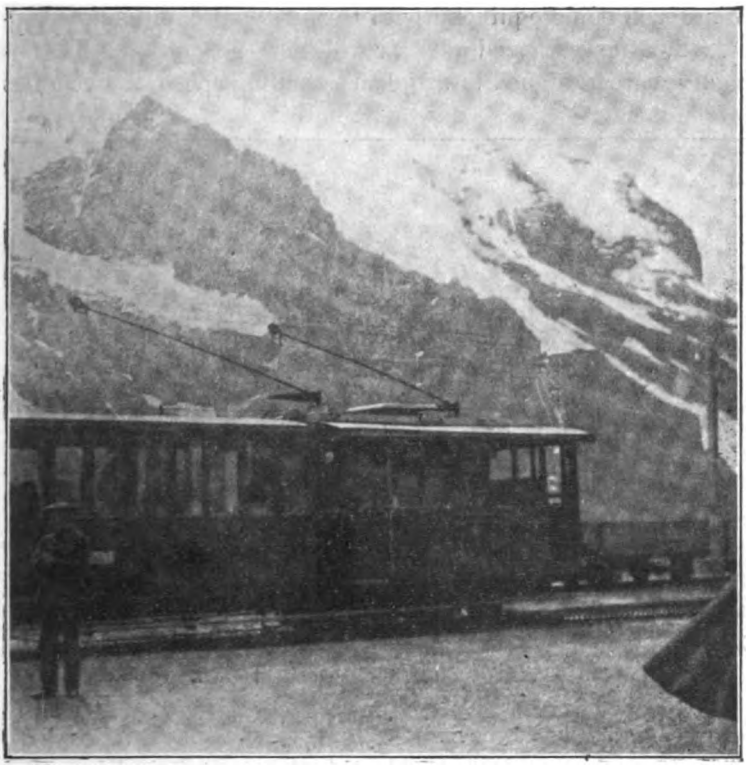

Fig. 48.—"Jungfrau" 3-Phase R. R. Locomotive.

been necessary to face the tunnel with stonework. About fifty H. P. is used for running eight three-phase current motors, for driving ventilators, pumps, etc. in the tunnel work, and continuous current is also used for operating boring machines on the electrical percussion solenoid principle. The transformers consist of three vertical iron cores, on which the primary and

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secondary coils are placed co-axially over one another. They are of 200 K. W., and give a secondary voltage of 500 volts.

In Figs. 47, 48 and 49 are shown types of the electric locomotives employed on the Jungfrau road. There are five locomotives. Two of them were made by Brown, Boveri & Co. of Baden, with an individual weight of 13 tons, and each locomotive has two motors with a maximum output of 200 H. P. and a speed of 760 revolutions per minute; the other three locomotives were made by the Oerlikon Company of Zurich, and are each of 19 tons weight, each being equipped with two 220 H. P. induction motors with a normal speed of 500 revolutions per minute. The locomotives are designed to make an ascending speed of five miles

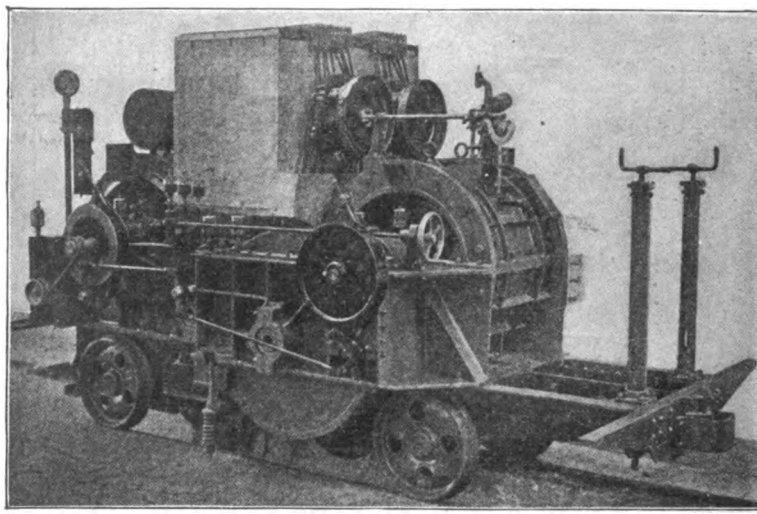

FIG. 49.—Showing "Jungfrau" locomotive construction.

an hour and draw two cars seating eighty persons. These motors are connected by a double reduction gearing. A sprocket wheel having teeth 4″ pitch and 2⅜″ broad, of aluminium bronze, engages a continuous "Strub" rack laid between the rails of the road. This rack is put down in ten feet sections, its height above the ties is about 7″, the pitch 4″, the breadth of the teeth is 2½″ and the tooth depth 2½″. The rails are of steel, 42 lbs. to the yard and 32 feet in length, and the gauge 3.28 ft. In the open they are laid upon wood ties and in the tunnel upon cast iron ties. A controller cuts resistance in and out of the rotor circuits, which

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resistances are kept cool by air forced through them by a ventilating fan driven by a three-phase induction motor. In the first locomotives built by Brown, Boveri & Co., one resistance was used for two motors. This had the disadvantage of producing "hunting," but the locomotives of this firm worked satisfactorily from the very beginning notwithstanding the heavy duty to which they were subjected. In the later Oerlikon types each motor has a separate resistance, which was used not only for starting, but also for absorbing current when the locomotive was descending, at which time the motors are left in circuit to secure the automatic braking action, and giving the generators a nearly constant load. These descending locomotives may at times supply current to the line, thus assisting the ascending cars. The locomotives will start themselves on a grade of 25 per cent. By mounting one end of a car on an extension of the locomotive frame the traction has been favorably increased, and to secure the greatest benefit of this weight the cars are put in front of the locomotive in going up hill, and behind it in descending.

It was customary at one time before descending, to signal the Lauter-brunnen power house, and resistance was put in circuit, but later the locomotives were equipped with a resistance qualified to absorb the whole current generated by the motors in descending. This saves wear and tear on brakes and turbines, generators, etc., and wastes no extra power as the water must pass the power house at any rate.

The cars are equipped with hand, automatic and electric brakes, as required by Swiss Mountain regulations. One of these locomotives is shown in Fig. 49. Messrs. West-Kunz and Thorman in their report to the Jungfrau Railway Commission upon the relative advantages of employing three-phase transmission with rotary converter sub-stations and continuous current motors on the locomotives, as compared with the employment of three-phase current throughout, advised the employment of the latter for the following reasons:

1st, because of the greater simplicity of the regulating arrangements of the motors.

2nd, because of the automatic braking action in descending grades.

3rd, because of the expense and difficulty in maintaining sub-stations, employing rotating machinery, and assistants to relieve each other periodically.

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4th, because after very careful estimates had been prepared from manufacturers' actual prices, it was found that the first cost of the rotary converter method would be over 50 per cent. greater than that of a system in which three-phase currents only were employed.

Fig. 50 is a diagram of the wiring of the generating station and locomotives. When the road is completed it is proposed to transport the passengers 300 feet higher, to the summit, by means of an electric elevator, (which I show in accompanying lantern slides), upon which will be mounted a three-phase motor, carrying two pinions, working in racks on the side of the shaft.

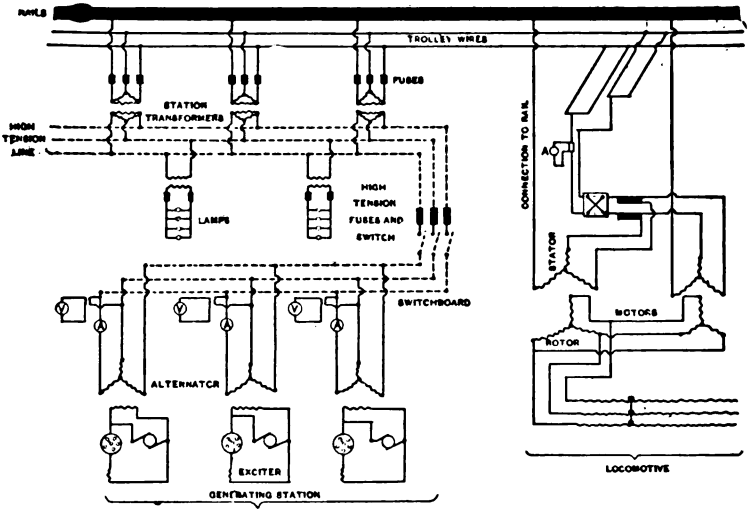

FIG. 50.—Diagram of Generating Station and Locomotive Circuits Jungfrau R. R.

The Jungfrau is 13,667 feet above the sea level and 11,808 ft. above Interlaken.

The electric road is now open from Kleine Scheidegg—which is 4,270 feet above Interlaken—to Rothstock, and although financial difficulties have recently delayed the work, it is expected that Eismere will be reached in 1903 and, as before stated, the road entirely completed between 1908 and 1910.

When completed the round-trip fare will be 35 francs or about $7.

The entire cost of the road when completed is estimated at $2,000,000.

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The distance from the commencement of the electric line to the tunnel is about six miles.

At each of the transformer sub-stations, which are in the main cut out of the solid rock, space is given for three transformers, for the necessary switches, instruments, etc., all of which are carefully insulated by glass or porcelain.

There are special sub-stations at Kleine Scheidegg and at Eigerglacier, containing an additional transformer of 40 K. W. and a rotary transformer of the same capacity, and also a set of storage batteries. These can be used in case of breakdown or stoppage, and for lighting the buildings, supplying the tunnel work, etc.

A difficult problem has been to satisfactorily reduce the speed of locomotives going down hill, which always exceeded the ascending speed by reason of the fact that three-phase generators run faster as generators than as motors. The Oerlikon Company has neatly solved the difficulty by attaching a small direct-current dynamo to the motor-shaft and supplying a direct current to the stator windings of each motor; a resistance placed in circuit permits the regulating of the direct current and secures a speed about half that of ascending. When the locomotive starts to descend, the over-head trolleys are lowered, and the three-phase current generated by the rotor is absorbed by the motor-starting resistance, which is much less than formerly. This brake arrangement has displaced the magnetic brake, which is only in circuit when going uphill.

The two rack pinions are 28″ at the pitch drain, the number of teeth 22 and pitch 4″. At either side of the rack pinions, are grooved wheels 4″ broad, each with four V-shaped grooves, into which fit iron clamps at both sides of the horizontal drain. Thus by turning either brake-handle, the brake acts at eight points simultaneously at both ends of these axles on the spur-wheels of the second gear; the reduction is 2 to 1 and the pitch 1″; the reduction by the first gear is 5.6 to 1 and pitch slightly less than 1″.

It is said that before 1851 but five successful attempts were made to ascend the Jungfrau, and while many plans have been suggested for carrying the public to the summit, it remained for the celebrated engineer, Mr. Guyer Zeller, to bring forward the first practicable plan. This was in 1893, and in the following year he was granted the necessary franchise to carry out the

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work, which he prosecuted with great energy and skill until his death in the year 1899.

The author has visited other important Swiss three-phase electric railways, but deems it inadvisable, by reason of the length of his paper, to present at this time data on others than that most interesting and typical road the "Jungfrau." He will, however, show some interesting lantern slides of the Stansstadt-Engelberg and Burgdorf-Thun three-phase Swiss mountain electric railways.

Discussion.

The President:—The paper is now open for discussion, but before it begins I would like to call attention to something which Mr. Hammer did not mention, and which may also interest you as one of the recent electrical novelties from Europe. It is what might be called a "Nernst arc lamp," that is, an arc sprung between pencils of heated porcelain. One of the most interesting features about it, is that it is claimed to be extremely efficient, much more so than the usual arc lamps; the difference in efficiency between it and the present arc lamp is much greater than between the Nernst incandescent lamp and the ordinary incandescent lamp. The efficiency is said to be about five or six candles per watt and it is claimed that this is equal to the mechanical equivalent of light. This, if true, would mean that it is the maximum efficiency which can ever be reached. Personally I believe this conclusion is based on errors, but nevertheless this new arc light is a very interesting experiment. The paper is open for discussion.

[Adjourned.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 22, 1901.

The 152d meeting was held this date at 12 West 31st Street, and was called to order by President Hering, at 8.30 P. M.

THE SECRETARY:—At the meeting of the Council this afternoon, the following Associate Members were elected:

Name.	Address.	Endorsed by
ALBIN, HENRY ALLISON	General Manager and Electrical Engineer, Concord St. Railway, Concord, N. H.	Chas. R. Cross. J. B. Smith. S. B. Paine.
BULL, ROBERT WILSON	Electrical Engineer, The New Jersey Zinc Co., (of Penn.) Palmerton, Pa.	Gano S. Dunn. F. V. Henshaw. Horace Dowie.
COOKE, GEORGE A.	Electrical Engineer and Supt., Hawaiian Electric Co., Honolulu, H. I.; residence, Chicago, Ill.	Wynn Meredith. A. M Hunt. A. Gartley.
EDMANDS, SAMUEL SUMNER	Assistant in Electrical Engineering, Ohio State University, Columbus, O.	F. C. Caldwell. H. B. Smith. E. E. Brown.
HOWE, WINTHROP KEITH	Assistant Engineer, Taylor Signal Co., 256 Delaware Ave., Buffalo, N. Y.	H. H. Wait. E. P. Warner. V. R. Lansingh.
JOHNSON, WALLACE CLYDE	Chief Engineer, The Niagara Falls Hydraulic Power and M'f'g. Co, Niagara Falls, N. Y.	J. F. Kelly. I. R. Edmands. S. B. Winchester.
MUDGE, ARTHUR LANGLEY	Electrical Engineer, Grand Trunk Railway Co., Montreal, Canada.	R. B. Owens. P. G. Gossler. R. M. Wilson.
PERRY, JOHN	President of I. E. E. (England) 84 Palace Gardens Terrace, London W. England.	W. J. Hammer. Ralph W. Pope. Carl Hering.
ROCKWOOD, DWIGHT CARRINGTON	Student, Westinghouse Elec. & M'f'g Co., Box 104, Edgewood Park, Pa.: residence, 954 Main St., Buffalo, N. Y.	Chas. F. Scott. John S Peck. H. L. Wallau.

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SPARKS, CHAS. PRATT	Chief Engineer, The County of London Electric Lighting Co., Surrey, England.	Wm. J. Hammer Ralph W. Pope. Carl Hering.
STRONG, JAMES REMSEN	President, The Tucker Electric Construction Co., 35 South William St., N. Y.; residence, Short Hills, N. J.	H. A. Sinclair. T. C. Martin. W. D. Weaver.
SWINTON, ALAN ARCHIBALD CAMPBELL	Consulting Electrical Engineer, 66 Victoria St., London S. W. England.	Wm. J. Hammer. Ralph W. Pope. Carl Hering.
THOMAS, JOHN WILLIAMS	Construction Engineer, Electric Storage Battery Co., Hokendauqua, Pa.	Louis Duncan. C. T. Hutchinson Leonard Waldo.
THOMSON, GEO. ANDROS	Special Agent, The Adams-Bagnall Electric Co., 26 Cortlandt Street, New York; residence, Somerville, N. J.	J. J. Bellman. F. M. Pedersen. Horace Dowie.
VAN VLEET, ROY MITCHELL	Student, Westinghouse Elec. & M'f'g Co., Edgewood Park, Pa.; residence, Port Huron, Mich.	H. L. Wallau. Chas. F. Scott. Jno. S. Peck.

Total 15.

The following named Associate Member was transferred to full membership:

Approved by Board of Examiners, February 8th, 1901.

ARTHUR L. HADLEY,	Electrical Engineer, Fort Wayne Electric Works, Fort Wayne, Ind.

At the meeting of the Council this afternoon, the following names were selected as the Council nominations for the coming election.

For *President*, Charles P. Steinmetz; for *Vice-Presidents*, Samuel Sheldon, George F. Sever, Michael I. Pupin; for *Managers*, John W. Lieb, Jr., Charles F. Scott, Samuel Reber, W. E. Goldsborough; for *Treasurer*, George A. Hamilton; for *Secretary*, Ralph W. Pope.

THE PRESIDENT:—The paper of the evening which is next in order is on the "Distribution and Conversion of Received Currents," by Henry Gordon Stott. I will call upon Mr. Stott to read his paper.

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A paper read at the 152nd Meeting of the American Institute of Electrical Engineers, New York, March 22nd, 1901. President Hering in the Chair.

THE DISTRIBUTION AND CONVERSION OF RECEIVED CURRENTS.

BY HENRY GORDON STOTT.

Before proceeding to the subject proper of this paper it will be interesting to give a brief description of the apparatus and lines generating, transforming and conveying the current from Niagara Falls to the Terminal House at the city limits of Buffalo, where the overhead lines terminate and the underground distributing system for the various purposes to be hereafter described, begins.

The power received in Buffalo originates at the well known plant of the Niagara Falls Power Company at Niagara Falls, N. Y., in water driven turbines direct connected to 5,000 H. P. two-phase 2,200-volt 25-cycle generators. Ten of these generators are now installed, and a new wheel pit is being excavated on the south side of the surface canal, parallel to the present power house, for twelve more generators of the same size, which will give an ultimate total capacity of 110,000 H. P., and it is a very safe prophesy to say that every horse-power of it will be sold as fast as the turbines and generators can be installed, as the present installation of 50,000 H. P. is all contracted for, and already many customers find themselves in the position of Oliver Twist, and with no better results.

The 2,200-volt two-phase current is conducted into the Transformer House, where, after passing through time element overload circuit breakers, it enters two distinct banks of step-up transformers of the air cooled type, of an aggregate capacity of 12,000 K. W., which are arranged in pairs for the two-phase

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three-phase connection at the same time to change the pressure to 11,000 volts. Within a couple of months the secondaries, which are now in multiple, will be connected in series to give 22,000 volts as originally intended.

The 11,000-volt three-phase current from the secondaries of the two banks of transformers is brought directly out in cables on large special porcelain insulators set in iron fixtures in the air chamber, and then on the regular helmet type porcelain insulators on timbers on the wall. The lightning arresters are of the usual multi-gap type with reactive coils in series, and in a second type with an additional check to the current in the shape of carbon resistances to prevent the live current following the lightning discharge.

The two three-phase 11,000-volt circuits running on the same pole line to Buffalo, each consist of three bare stranded copper cables of 350,000 cm. area, forming equilateral triangles on each side of the pole, the sides of the triangles being three feet. In the run of 23 miles to Buffalo, the lines are transposed five times in order to equalize and minimize the inductive drop on all phases, and at Tonawanda where a branch line is taken off for Tonawanda and Lockport, lightning arresters are installed of a type similar to those used at Niagara Falls and Buffalo. During the first two years operation of this line, iron guard wires grounded at every alternate pole were used for protection from lightning, but so much trouble was caused by them falling on the lines that after striking a balance between the supposed protector and the known trouble, the result was so overwhelmingly against the former that the guard wires were taken down, and the interruptions due to line trouble very materially reduced. The remaining trouble on this part of the system was almost exclusively due to the ever present boy, who speedily discovered that by a little dexterity in the manipulation of an old piece of iron wire or hoop, he could produce brilliant Fourth-of-July effects at will. The cables were, at this time, only 18 inches apart, and an arc once established would travel backwards along the line with ease until the circuit breakers eventually opened at the Falls. This trouble was remedied very effectually by separating the cables three feet apart as at present, and at the same time arranging them so that they formed a triangle with the apex below instead of all being on the same plane as formerly.

At the Terminal House situated at the city limits of Buffalo, the lines now terminate in a common set of bus bars, and to these

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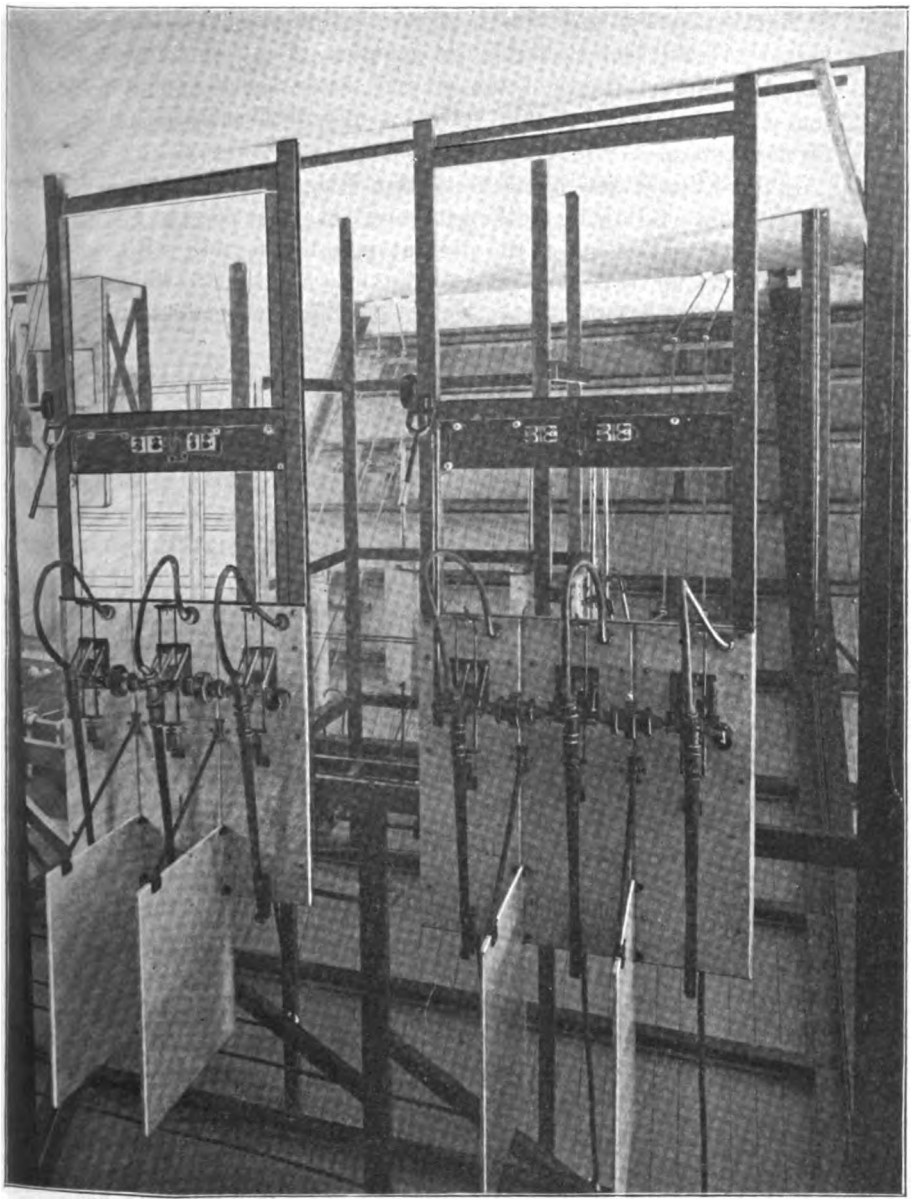

FIG. 1.

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bus bars are connected the five three-conductor lead covered cables which lead to the various sub-stations.

Simultaneously with the increase of line pressure to 22,000 volts there will be installed in the Terminal House six 2,250 K. W. step-down transformers of the oil and water cooled type, reducing the pressure to 11,000 volts for distribution in the underground cables.

A third line is now being built from Niagara Falls to the Terminal House, following a different route, in order to give greater security of service, but as the present pole line is built with very heavy poles 90 feet apart, no great anxiety is felt as to the possibilities of even Lake Erie zephyrs combined with sleet, affecting it.

Following the current as it comes into the Terminal House on the 22,000-volt lines, we first come to the lightning arresters which are of the well known multi-gap type, the connections to each line having a reactive coil inserted to prevent the rush of static discharge being followed by a greater current, from the line, than the gaps of non-arcing metal can interrupt by cooling off the air and extinguishing the arc at the zero period of the wave. As an interesting fact it may be observed that the number of 1/32″ standard gaps necessary to prevent the current arcing across under normal conditions is not directly proportional to the pressure, but increases in the same ratio as the arcing distance in air of a single gap.

The high-tension circuit-breakers shown in Fig. 1 are of a very simple form, but one which has invariably given excellent results, being simply a long hollow wooden arm containing a flexible insulated conductor, which completes the circuit through copper contact blocks, with auxiliary carbon contacts for breaking the arc on. When the circuit-breakers open, the arm describes the arc of a circle giving a break of over three feet, and as the arc ascends rapidly, due to the currents of hot air generated by it, the length of the arc is rapidly increased until broken. The position of the marble barriers above the panel illustrate the height to which the arc may be expected to rise in extreme cases. After passing through the circuit-breakers the current is led to bus bars, and from these to the two groups of transformers only three cables being carried from the panels to each group of three transformers, as the delta connection is made at the terminals. The low tension, or 11,000-volt secondaries are

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connected in the same way to the bus bars on the secondary panels, and from here the five three-conductor lead covered cables distributing the current to the various sub-stations in Buffalo, receive their current after passing through the usual recording and indicating meters and circuit-breakers of the same type as on the 22,000-volt side. All these circuit-breakers have a time element device which can be regulated so as to make the circuit-breakers open only after a short-circuit has lasted a predetermined number of seconds; similar devices are used on all over-

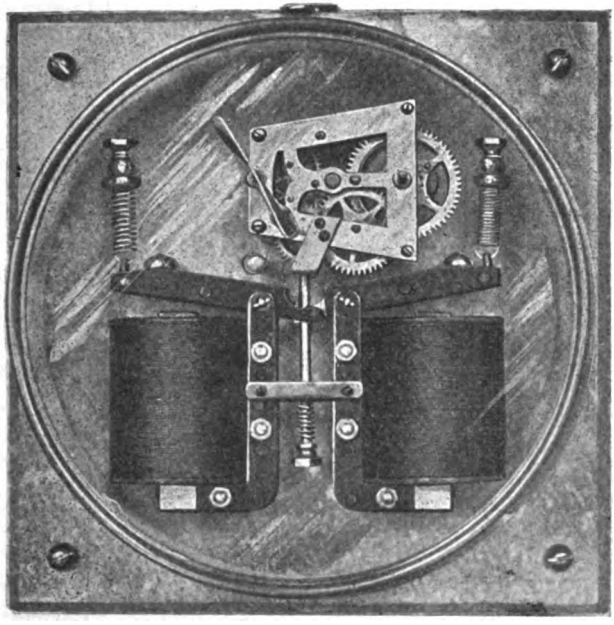

FIG. 2.—A view of one of the time element relays. The two coils are connected respectively with current transformers in two phases of the line. Either releases the clockwork which after a proper interval closes a local circuit through the tripping coils of the breakers.

load circuit-breakers, the time limit varying inversely as the distance from the source of power, in order to prevent the more distant stations shutting down the others.

We now come to the distribution and conversion of the current in Buffalo, but the scope of this paper will only permit of the more important and novel features being taken up and described in the briefest manner possible.

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Distribution.

Referring to the diagram, Fig. 5, showing the system of distribution connecting the seven sub-stations to the Terminal House, it will be seen that there are five three-conductor cables leaving the

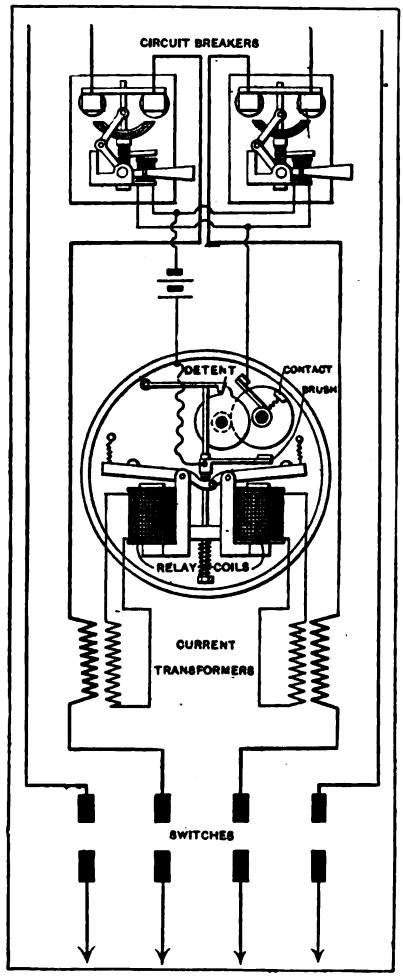

Fig. 2a.

Terminal House, each sub-station being connected to at least two cables, either one of which is capable of carrying the full load, and in the other stations having more cables, any two are capable of carrying the full load. The necessity for duplicate service to prevent shut-downs through cable trouble, is so obvious

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as to necessitate no further comment, but the automatic apparatus used to cut out the faulty cable is novel and interesting. Before describing the system, a brief description of the various circuit-breaking apparatus used will be in order.

Figure 1 shows a type of breaker used in the Terminal House and in sub-station No. 3, which has already been described; Figs. 2 and 2A, show one known as the shunted fuse type, in which the current is carried by a spring copper leaf brush which is forced into

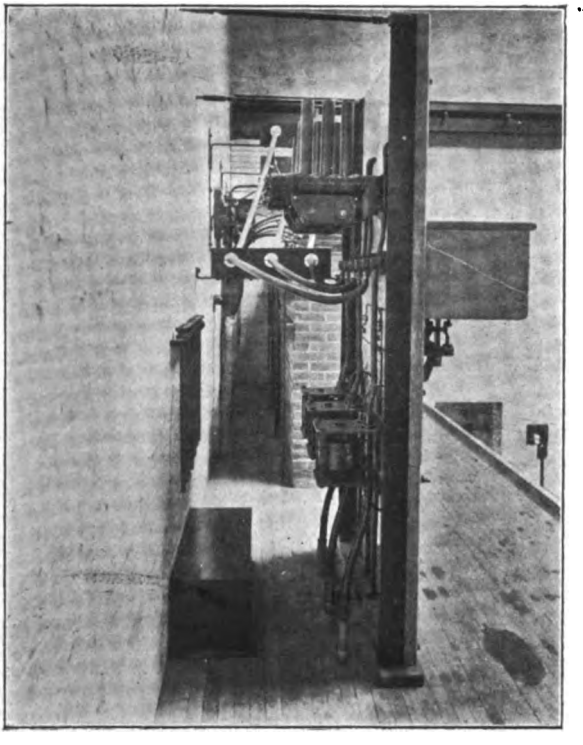

FIG. 2B.

contact with the copper blocks by means of a toggle joint lever. In shunt with this is a copper fuse wire 20″ long of No. 22 B. & S. gauge fastened in a groove in a stick having near each end brass contacts, which, when the fuse stick is forced into the receptacle mounted in the marble panel, forms a shunt on the circuit-breaker proper. The fuse stick is covered with fibre paper, and three holes are punctured through this paper, so that when the

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stick is in place in the enclosing wooden tube, the holes in the paper exposing the copper wire, are opposite three fibre chimneys. The gases formed by the melted copper escape with such force through these chimneys shown in Fig. 2B, that the arc formed after the circuit-breaker trips, is blown out with a noise resembling the report of a pistol.

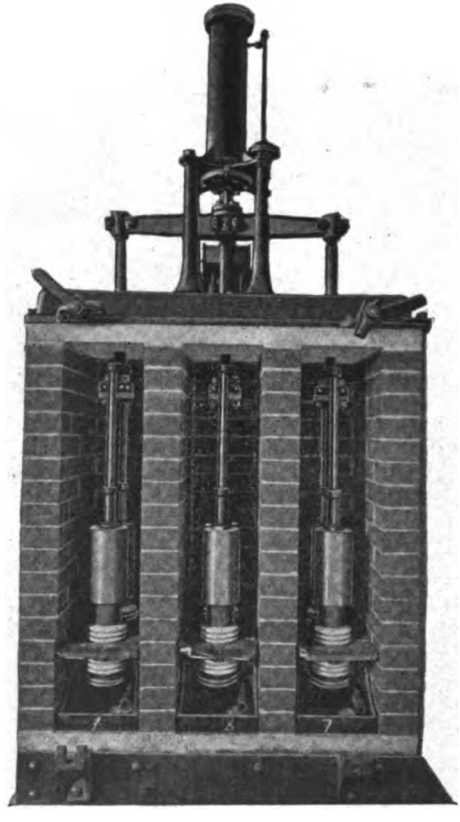

FIG. 3.

To reset the circuit-breaker, the switches in series with it are opened, the old fuse stick replaced by a new one, the circuit-breaker closed, and last of all the switches. This form of circuit-breaker has given excellent results on both 2200 volts and 11,000 volts. A time element relay is shown in Figure 2, which is used on the overload apparatus, the retardation being accomplished by a train of clockwork operated by an

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ordinary spring. The brake on the clock train (which is normally at rest) is released by either of the two magnets, one being connected to the secondary of a transformer in series with phase No. 1, and the other similarly connected to phase No. 2, the diagram showing the connections for a two-phase circuit. Variation of the time limit is accomplished by changing the angle of the air paddles on an axis normal to the spindle driving them.

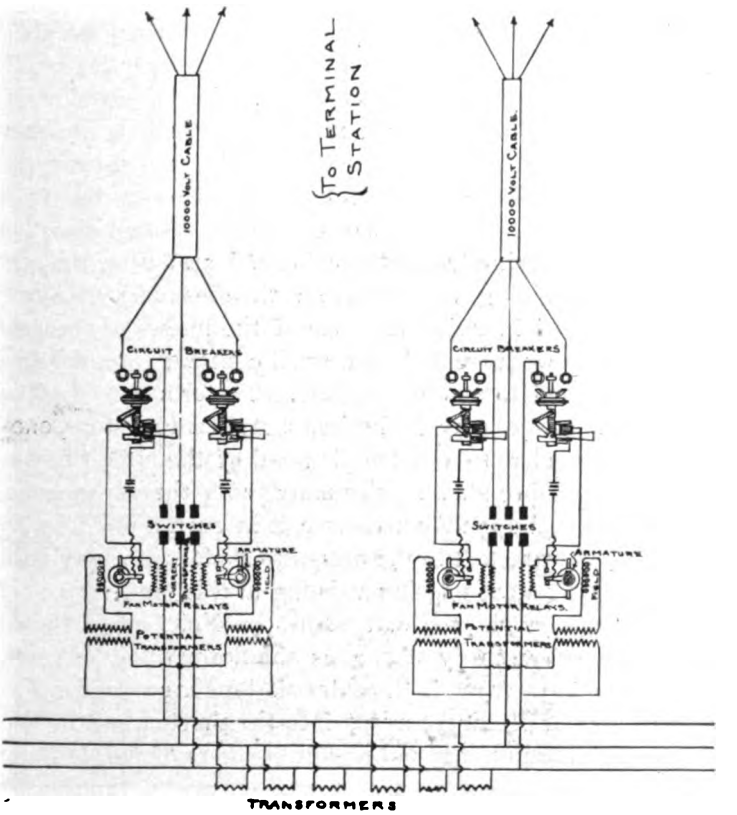

Fig. 4.

Figure 3 shows a third type of switch which may be operated by air, controlled by a relay or by any other agency, and consists simply of a U-shaped copper rod connecting two brass cylinders, with spring sockets, filled with oil. When the U-shaped rods are withdrawn from the copper receptacles at the bottom of the cylinders the arc is broken in oil in two places.

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The cut illustrates the separation of the phases by means of brick partitions, so that in case of failure a short-circuit cannot take place. These switches have also given excellent results on all pressures.

It is quite obvious that any sub-station supplied from two cables in multiple through overload circuit-breakers, is thoroughly protected from damage due to failure of the apparatus in itself, but a few moments' consideration will also show that it is not protected from a shut-down due to one of the cables supplying it becoming defective, and thereby causing the second cable's circuit-breakers to trip, from current supplied through them to the short-circuit in the cable. To obviate this, the reversed current circuit-breaker has been devised, and the connections are shown in Figure 4. The circuit-breaker proper is of the same type as those shown in Figures 1, 2 and 3, but the novelty lies in the means of tripping it. The relay consists of a small direct current fan motor having laminated fields and armature, the armature circuit receiving current from the secondary of a transformer connected in series with one of the phases of one cable, the fields receiving current from a small constant potential transformer connected to the same phase. The armature shaft carries an arm whose play is limited between two stops, one of which is connected to the tripping coil of the circuit-breaker, the other stop being blank. Normally with these connections the torque exerted upon the armature is in such a direction that the contact arm attached to the armature shaft is strongly pulled against the blank stop, a spring assisting in this pull.

Suppose that a short-circuit comes on No. 1 cable, the conditions are now radically changed; the normal flow of current into the bus bars from both cables no longer exists, for No. 2 cable will now be feeding current into the short-circuit in No. 1 cable through the bus bars and circuit-breakers of No. 1, thereby reversing the direction of the flow of energy in the armature circuit of its relay, and as the field remains the same as before, the contact arm swings over rapidly, completing the local circuit and tripping the circuit-breakers, leaving the sub-station bus bars connected to the good cable only. The same action will take place at all the sub-stations to which this cable may be connected, and finally the overload circuit-breakers in the Terminal House will cut out the faulty cable entirely.

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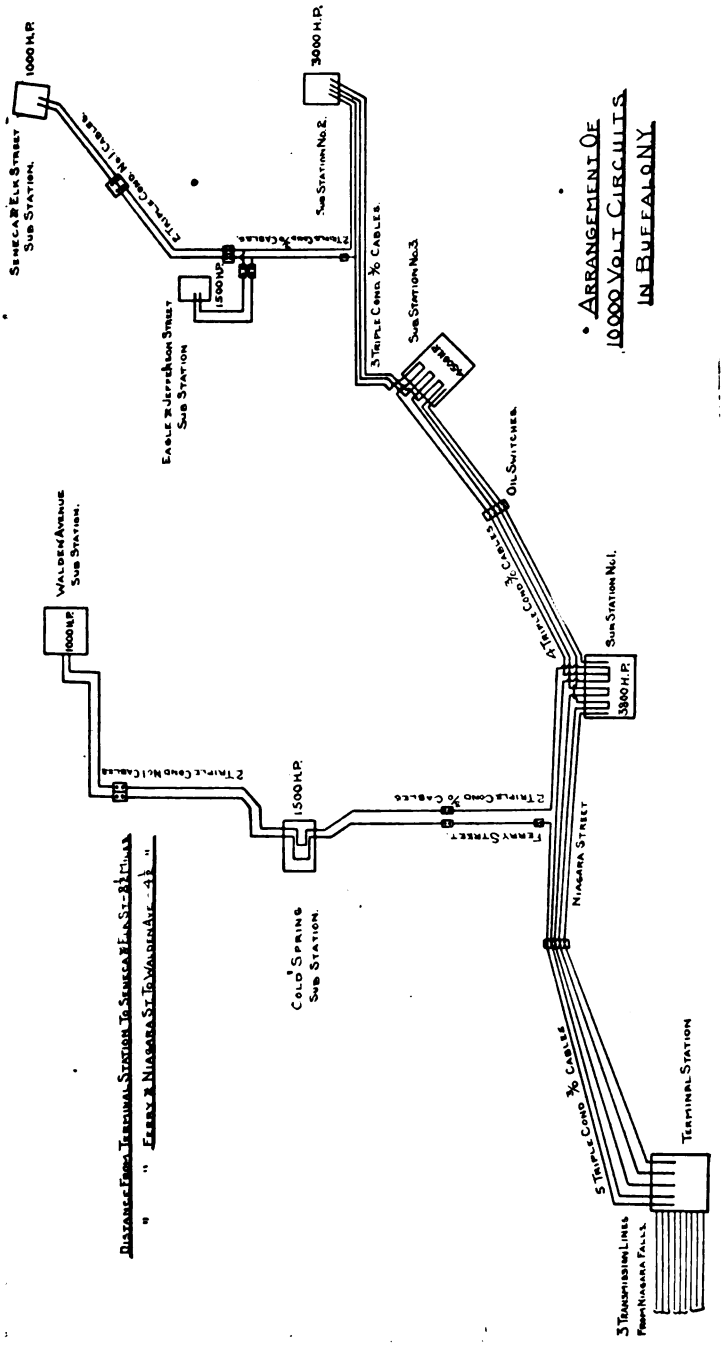
Seneca & Elk Street Sub Station.
1000 H.P.
Eagle & Jefferson Street Sub Station
1500 H.P.
Sub Station No. 2.
3000 H.P.
3 Triple Cond. ⅜ Cables.
Sub Station No. 3
Oil Switches.
Sub Station No. 1.
3800 H.P.
Ferry Street
Niagara Street
Terminal Station
3 Transmission Lines From Niagara Falls
Cold Spring Sub Station.
1500 H.P.
Walden Avenue Sub Station.
1000 H.P.
Arrangement Of 10000 Volt Circuits In Buffalo N.Y.
Distance From Terminal Station To Seneca & Elk St. 8½ Miles
" " Ferry & Niagara St. To Walden Ave. 4½ "

FIG. 5.

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The five cables shown in Fig. 5, connecting the Terminal House with the sub-stations are all of the 3-conductor type, that is, have three 000 B. & S. gauge copper cables separately insulated under one lead covering, the three insulated conductors being twisted into a rope, and the interstices filled with jute yarns to give an even round surface for the lead to rest on.

Three of these cables are insulated with a wall of 9/32″ rubber mixture having 30 per cent. of pure Para rubber; one has a wall of ¼″ rubber mixture with 40 per cent. pure Para, and the fifth cable has on each conductor 13/64″ paper, and around the three insulated conductors an additional belt of 13/64″ paper. All the cables have a lead jacket ⅛″ thick, over all, the outside diameter of cables being approximately 2⅜ for the rubber and 2⅝ for the paper.

Experience with the first four cables seems to indicate that a rubber insulated cable with 9/32″ wall, 30 per cent. pure Para, is perfectly reliable for 11,000 volts, but that ¼″ insulation even with a higher percentage of pure Para is not.

The 18 miles of paper insulated cable having only recently been installed, no conclusions can be drawn with safety, but as there are about 30 miles of the rubber covered cables which have been installed for from two to three years, the above conclusions would seem to be drawn from experience with a sufficient amount of cable to justify confidence in its reliability.

In the sketch showing the cable system it will be noticed that at several points "oil switches" are indicated; these are installed in water-tight iron boxes in the manholes, in such positions as to break the cables into sections of about one mile in length, so that in the event of trouble the fault may be readily localized and the bad section switched off in the manholes without interfering with the rest of the cable.

Glazed tile conduits are used, and have proved, when dry, to be an effectual safeguard against electrolysis, the only cases of trouble from the latter having occurred in manholes in which the cables were submerged in water. Considerable trouble was caused for a time by the breaking down of the rubber near the end of the lead covering where the cables were connected to the switchboards, and investigation showed that this was caused by the ozone generated by the static discharge taking place from rubber to lead, but this has been overcome by wiping on a large brass cable head to the lead sheath and thus greatly increasing

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the distance between rubber and grounded sheath, the cable head being filled with insulating compound poured in hot, a hard rubber separator keeping the rubber covered conductors away from the brass whilst the compound was solidifying. Reference to the diagram Fig. 5, will show that a further precaution has been taken at the two most important sub-stations, Nos. 1 and 3, to prevent interruption due to cable trouble, viz., to run loops from all cables into them instead of taps. By this means, if a fault should simultaneously develop in a section of one cable between these stations and in a section beyond either of them, cross-connections can be made very rapidly and easily, by means of which no cable will be overloaded for more than the short period necessary to make these cross-connections.

To sum up: The means adopted for protection to the distributing system are:

1. Time element overload circuit-breakers.
2. Reversed current circuit-breakers.
3. Sectioning switches in manholes.
4. Loop switches in principal sub-stations.

Conversion.

The 11,000-volt 25-cycle three-phase current distributed to the seven sub-stations in Buffalo is manifestly unfit for use in the supply of power or light without transformation in the former and conversion in the latter case, as 25-cycle is much too low a frequency for arc lighting, which promises to displace incandescent lamps to a great extent in the near future.

In discussing the various means employed to make this power available to the customer, we will begin with the simplest and then proceed to the more complex. The simplest and most efficient method is evidently to reduce the pressure by means of static transformers of large capacity and high efficiency, and deliver three-phase 2200-volt current to the various customers by means of a secondary network of cables. This is done in sub-stations Nos. 1, 2 and 3, where 2200-volt three-phase current is delivered by underground and overhead cables to customers for use in malt houses, grain elevators, machine shops, dry docks, bakeries, tanneries and all sorts of manufacturing establishments to the extent of about 4,000 H.P. This power is utilized in the above places chiefly by means of induction motors, some of which receive the current directly at 2200 volts, but in the ma-

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jority of cases at a reduced pressure of 440 or 220, the reducing transformers being supplied by the customer. For grain elevators, in which a large amount of fine dust of an explosive nature is present, the induction motor presents an ideal solution of the power problem as the safety and controlling devices can be located in a separate building, so that no spark can cause an explosion or fire. The efficiency of transformation with this system is evidently that of the transformers only, which in sizes of 250 K.W. and upwards is from 97.5 to 98.3 per cent. at full speed.

The largest user of power in Buffalo is the International Traction Company, which receives a total of 7000 H.P. in five sub-stations, No. 1, Cold Springs, Walden Avenue, Eagle and Jefferson streets, and Elk and Seneca streets, where the power is distributed to their 550-volt direct current feeders after being transformed from 11,000 volts to 375 volts and converted in rotary converters to 600-volts direct current.

An interesting comparison is the relative efficiencies and cost of static transformers and rotary converters as against motor generators receiving the 11,000-volt current direct into the motor, and converting it into 600-volt direct current by means of a generator coupled to the same shaft, and is given in the following table:

EFFICIENCIES: 200 K.W. UNITS.

	Transformer	Rotary	Combined	Motor	Generator	Combined
Full load	97.5	93.0	90.67	95	92	87.4
¾ load.	97.1	92.5	89.81	94	91	85.54
½ load.	96.0	90.0	86.40	92	88.5	81.42

From the above table it will be seen that the transformer and rotary converter give 3.27 per cent. at full load, 4.27 per cent. at three-quarter load and 4.98 per cent. at one-half load better efficiency than the motor generator set.

The investment shows a saving in favor of transformers and rotary converters of about 19 per cent., so that for purposes such as railroad work, where no great refinement of regulation is required, the rotary is beyond doubt the best and most economical.

A view of a sub-station is given in Fig. 6, which is typical

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of all; the incoming current enters a three-pole oil switch, which is known as an emergency switch, and from there branches to several oil switches, each of which controls the primaries of three 150 K. W. static air-blast transformers connected in delta; the secondaries, also delta-connected, go direct to the collector-rings of a 400 K. W. rotary converter, so that the three static transformers and rotary converter form one unit, being in fact started from the direct-current end and synchronized by means of small potential transformers on the 11,000-volt primaries.

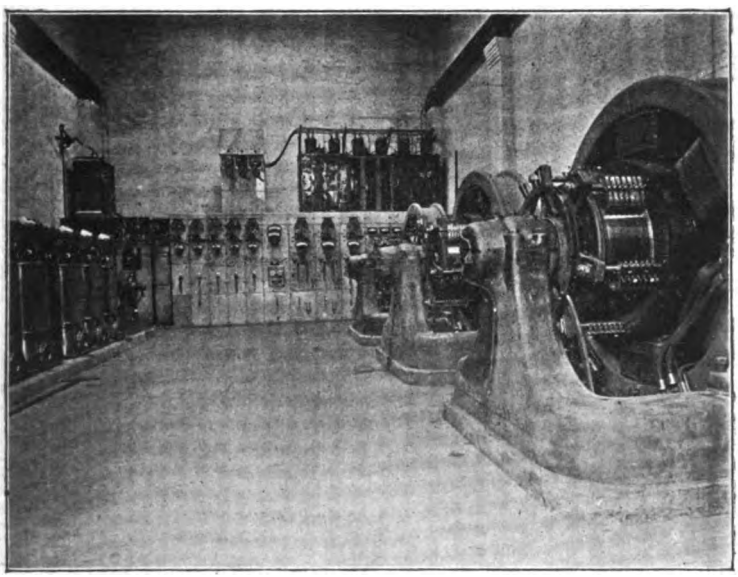

FIG. 6.

To provide for the emergency of a total shut down of the power circuits, those sub-stations which have no storage battery auxiliary from which direct current may be got for starting the rotaries, a small motor generator set is installed, consisting of a 30 H. P. induction motor direct-connected to a 20 K. W. 600-volt direct-current generator. This set is supplied with alternating current by means of a three phase oil-cooled transformer, reducing the pressure from 11,000 to 375 volts; as soon as the power is on the cables the induction motor is started, the small direct-current generator is connected to the

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bus-bars and one of the rotaries started and synchronized in the usual way, after which the motor generator set is shut down and the remaining rotaries started from the first. From the five sub-stations distributing power to the direct-current feeders great economy of distribution is obtained and an equality of pressure at practically every point of the system, which would be practically impossible with a single plant with 550-volt feeders covering the same distance. Storage batteries are installed at Sub-stations No. 1, Cold Springs and Eagle and Jefferson, having a total capacity for 1½ hours of 2,400 H. P.

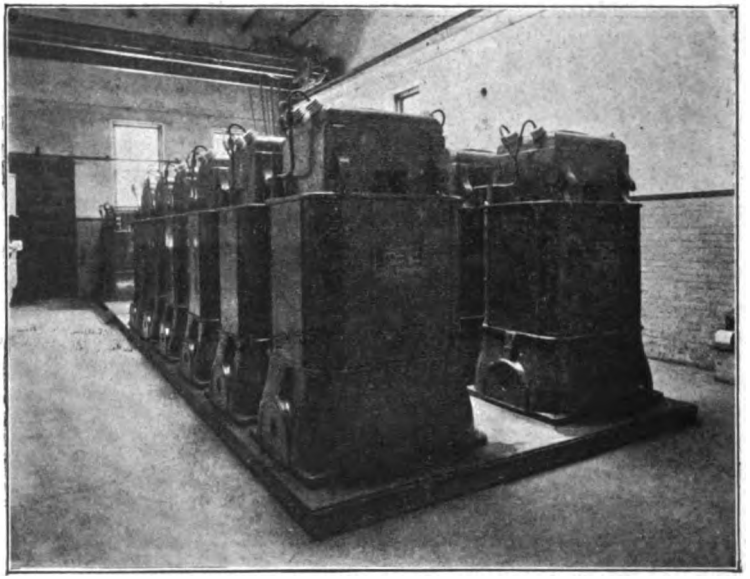

FIG. 7.

at 575 volts. They are used principally to help carry the peak load between 5 P. M. and 6.30 P. M. and to take up part of the extreme fluctuations of load through differentially wound boosters.

We now come to the last and most interesting plant connected to the transmission system in Buffalo, viz., that of the Buffalo General Electric Company, the transformer-house of which is marked "Sub-station No. 3" on the sketch showing cable system, in which 4,000 H. P. is received from the power company, and after being transformed to 360 volts is con-

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verted, by means of motor generator sets, rotaries, etc., into four different kinds of service—constant continuous current for street arc lighting, 60-cycle quarter-phase current for incandescent and arc lighting in the more remote districts, three-wire 220-volt continuous current for the down-town district, and 550-volt continuous current for power to motors, elevators, etc.

The transformer-house, built as an annex to the main station, has twelve 250 K. W. transformers, reducing the three-phase

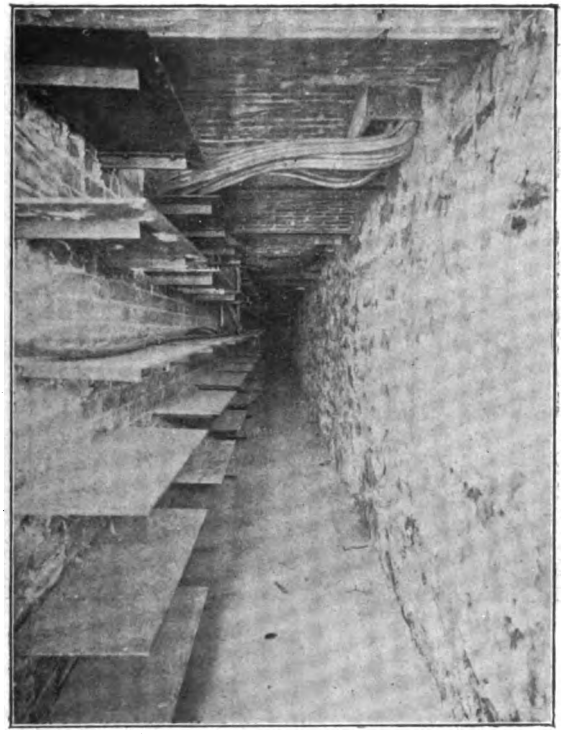

FIG. 8.

11,000-volt current to three-phase 360 volts. The transformers [see Fig. 7] are arranged in two rows instead of three as usually in order to facilitate the rapid exchange of one in case of trouble. By arranging them in this way the transformer has only to be raised half an inch by the hand-crane and then run out of the way to make room for the spare one, an operation requiring only an extremely short period compared to that necessary to

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lift the transformer over the others. The transformers stand over a brick air-chamber 30′ x 9′ x 7′ high, into which three 2 H. P. induction motors direct-connected to air-blowers force cool air, giving an even pressure of about half an ounce in all parts of the chamber. Access is had to the air-chamber through double air-tight doors, so that a man can work on the terminals or connect up a new group without interfering in any way with the air supply. Iron shelves on the outside of the brick walls of the air-chamber form supports for the primary cables leading to the switchboards on the one side and for the secondaries on

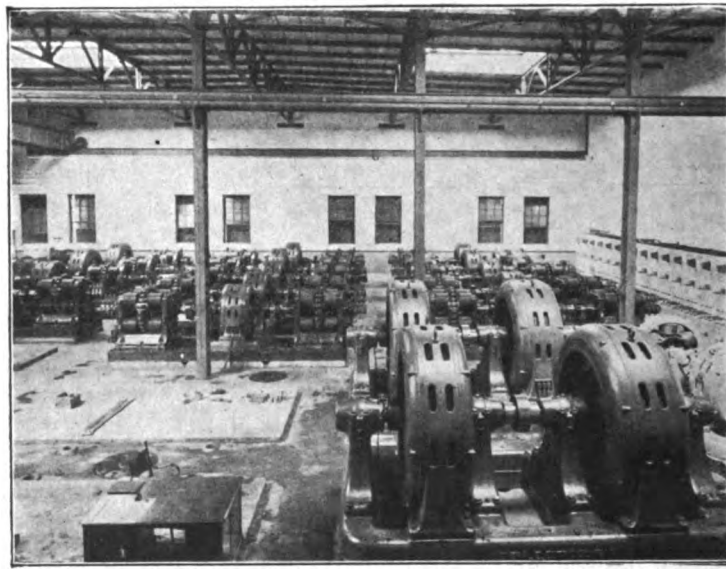

FIG. 9.

the other, giving wide separation for safety, similar to those in Fig. 8.

The transformers are connected to the primary and secondary switchboard panels by rubber insulated and lead covered cables; each transformer is wired single-phase to the panels, the delta connection being made after passing through spring expulsion type aluminium fuses on the primary side, and ordinary long break aluminium fuses with barriers on the secondary side, so that in the event of a transformer burning out it will cut itself out of circuit without affecting the other two of the same group.

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The secondary current after going through the usual recording and indicating instruments, terminates in three heavy copper bus bars, extending the full length of the secondary board, to which are attached the cables bringing the current into the main building of the Buffalo General Electric Company.

In adopting the secondary voltage of 360, a number of points were taken into consideration, the principal one being that a large and healthy day load in 550-volt direct current motors was being supplied at the time steam was used for motive power, and could not well be discontinued, so that voltage was adopted which would permit of rotaries being run without any further transformation. This pressure besides being very safe for cables and motors, is a very economical one to build for, as it permits of the use of bar winding on all sizes, and as all motors are of the revolving field type, the question of carrying heavy current in the collector rings was left out. The only additional cost due to the low pressure was in the cables within the plant, and this was more than balanced by the saving in a further transformation for the 550-volt rotaries and in the additional safety of bar winding versus wire.

The power house, Fig. 9, is a building 91′x91′, having a row of columns down the center, each half of the building being spanned by a crane traveling the full length with transfer points from one crane to the other.

In this building having 8281 square feet of floor surface are installed 6460 H. P. in motors, 6073 in generators, and 600 H. P. in rotaries, a total of 13,133 H. P. in electrical machinery, giving a floor space of 0.63 square foot per H. P. or 1.24 square feet per H. P. of generating capacity, including all regulating apparatus, switchboards, etc.

Apparatus for Street Arc Lighting.

At the present day if the problem of arc lighting for street purposes with 25-cycle three-phase current supplied, were to be placed before an engineer, several methods of solution would suggest themselves in the following order: 1st, rectifiers; 2d, motor generator sets, converting to 60 cycles constant potential with some form of transformer or reactive coil to regulate for constant current; 3d, motor generator set converting to constant continuous current; 4th, motor generator set converting to constant alternating current with series transformers and condensers.

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The full load efficiencies of the four systems with comparative investments and full power factors are approximately as follows:

1	2	3	4
Rectifiers.	Motor Generators 60 Cycle.	Motor Generators Constant D. C.	Motor Generators Constant A. C.
88	88.94	78.9	86.6% Efficiency.
53	100	94	94 % Investment.
70	100	100	100 % Power Factor.

From the above table it will be seen that the rectifier leads in all respects save one, viz., power factor (the power factors given are those of the 25-cycle end, the receiver power factor

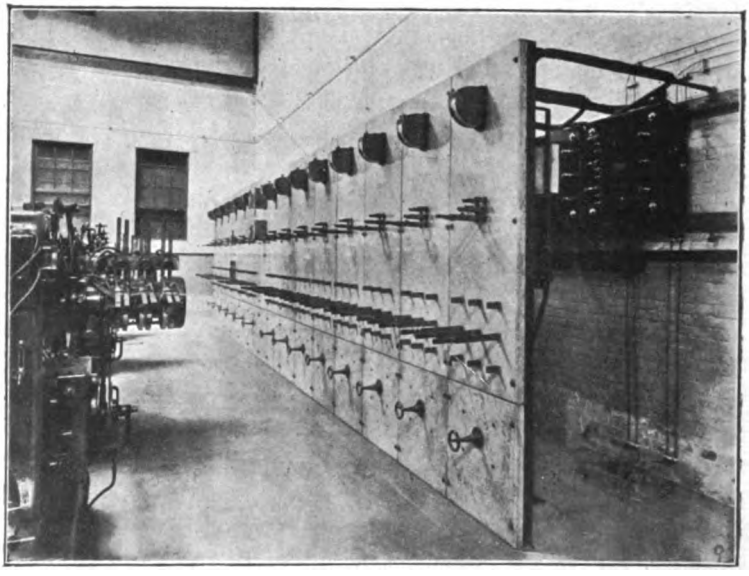

FIG. 10.

being of small importance), but in a system where the arc lighting forms a considerable portion of the system this is a serious feature, especially with generators not having good inherent regulation.

Owing to existing contracts with the city, the company was forced to adopt the third plan, but after the expiration of the present contract it will probably adopt the fourth plan, installing enclosed A. C. lamps.

The arc lighting equipment at present consists of 14 motor generator sets, each set consisting of one 150 K. W. revolving

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field type three-phase synchronous motor direct-coupled to two 125-light 9.6 ampere Brush arc generators, the motor being in the center, with a generator on each end, coupled by means of a very simple but effective type of insulating coupling, consisting of four arms or spiders on the motor-shaft and a similar number on the generator, compressing spring rubber rolls $3\frac{1}{2}''$ in diameter by $4\frac{1}{4}''$ long between them.

These motors are started in a very simple manner. The switchboard panel, shown in Fig. 10, controlling each motor, has mounted on it one ammeter, one double pole field switch

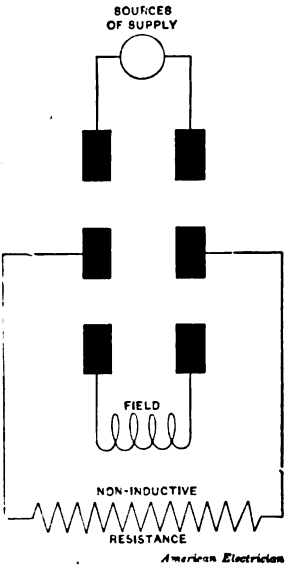

FIG. 11.—Circuits of switch shown in Fig. 10.

with discharge resistance as shown in sketch, Fig. 11, three single pole double throw knife switches and a rheostat. The fuse base is mounted on the back. Fastened to the wall behind each panel are the reactive coils for starting the motor.

To start the motor the three single pole switches are thrown down, thus connecting the motor armature to the bus bars through the reactive coils; the motor comes up to full speed in about 50 seconds, taking at the start about 150 per cent. full-load current. The time of attaining synchronism is determined by touching the blades of the field switch connected to the revolving fields on the discharge resistance clips and noting

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if any spark occurs. In the absence of any, the field switch is closed, exciting the fields and the single pole double throw switches turned up one at a time (the motor running single-phase meanwhile).

The spark at the discharge resistance terminals is of course due to the difference in frequency or slip between the impressed frequency and that due to the speed of the motor. At the start this gives about 2,200 volts, dying down in inverse ratio to the speed attained, to zero, at synchronism.

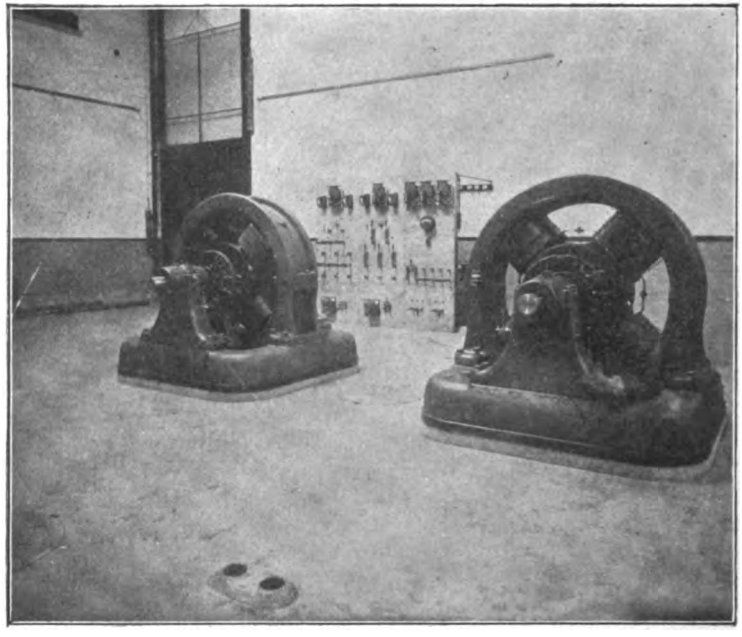

FIG. 12.

550-VOLT POWER SERVICE.

The 550-volt power service is supplied from rotary converters [Fig. 12], in the usual way, calling for no comment beyond the method of starting from the A.C. end which is done in exactly the same way as in the synchronous motors; the fields being stationary, a multiple blade switch is mounted on the frame of the machine to isolate each field winding, and thus break up the induced E M.F. at starting.

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60-Cycle System.

Three 500-K.W. three-phase synchronous revolving field type motors direct connected to 500 K W. revolving field 2200-volt quarter phase generators, furnish the current for this system. The feeders are connected to double throw oil switches, so that they can be thrown from one phase to the other to balance up the load, a further control of the voltage being obtained by means of regulators on each phase. Some rather unusual prob-

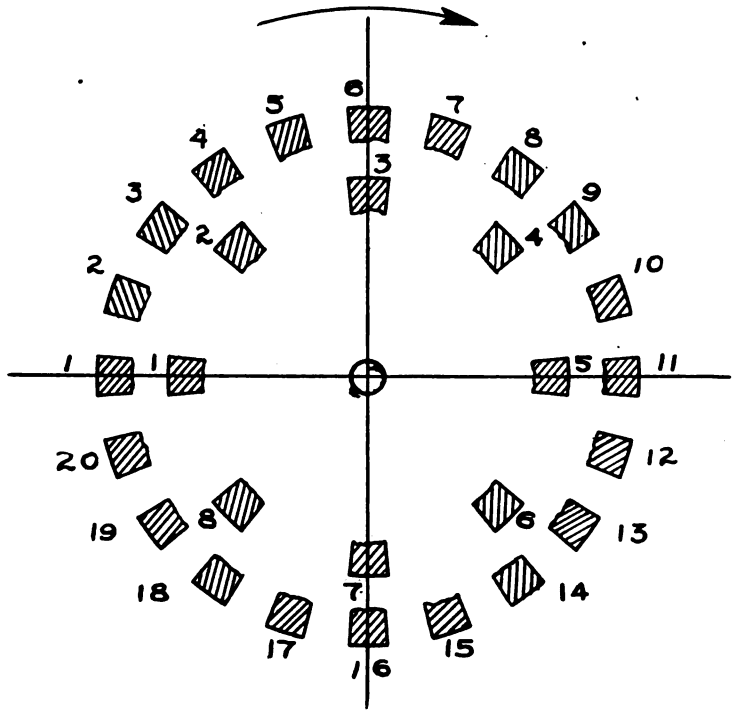

Fig. 13.

lems presented themselves in synchronizing these 60-cycle generators. The motors having eight poles and the generators 20, it is evident from the sketch, Fig. 13, that only every fifth pole of the motor will be the proper point to lock at. At first it was supposed that by opening the field switch on the motor that it would slip a pole when the generator field was excited, and the whole iron losses acted as load, but the voltmeter showing the resultant voltage between the bus bars and the ingoing genera-

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tor refused to move. The synchronous motor was too good a hysteresis and reaction motor, but the solution was found in putting in a reversing field switch on the motor, thus causing it to slip a pole on each reversal. The inner circle, shown in Fig. 13, represents the motor poles, and the outer the generator. If the generator carrying load has its poles in the position 1, 1, at the moment the field switch on the motor about to go into service is closed, and the latter locks with 1, 1, in the position of 4, it is evident that we must reverse the motor fields several times in order to make it slip back to position 3, then 2, and finally 1. Whilst the position 3, 6, has a similar relation to the generator pole, to that of 1, 1, yet the polarity is reversed on the generator so that unless we reverse the generator field also, the motor must be made to slip to position 1, 1. Another peculiar feature was that supposing the bus bar voltage and that of the ingoing machine to be the same, and the machines apparently in phase, if thrown together the ingoing machine would not take more than a small fraction of the load, and no change of field strength of either motor or generator had any effect, beyond making the generator carry idle current.

We have here the peculiar combination of double synchronism, with mechanical connection besides, so that either machine may act as motor or generator according to conditions. The explanation is as follows:

The motor carrying the load sags behind a few degrees of phase, carrying with it the generator, but the latter having 2.5 times the number of poles of the motor, any sag of the motor is multiplied by 2.5, thus causing a difference of phase between the loaded generator and the unloaded one great enough to render division of load impossible. Increasing the field strength of the light generator merely results, under these conditions, in the unloaded generator supplying idle cross current out of phase with the bus bar current, and therefore not putting load on its own motor. Manipulation of the motor field rheostats can evidently accomplish nothing to bring the generators into phase.

The solution is a rather startling one, and is found in the use of oscillating currents. The in-going generator is excited to such a degree that the resultant voltage from it and the bus bars is equal to the latter; this means at half load on one, and the other light, an increase of 4 per cent. in voltage, indicating

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a phase angle difference of about 22.5 in the generators and 9° sag in the motor. The motor fields are weakened and the unloaded generator thrown on the bus bars. Owing to the difference of voltage and phase, the sudden closing of the circuit establishes strong oscillatory currents between the generators; these are transmitted mechanically to the motors and repeated, the amplitude gradually decreasing from a maximum value of 100 per cent. full-load current to zero as the equilibrium of the circuit is established. The whole time, from the moment of putting the unloaded generator into multiple to the disap-

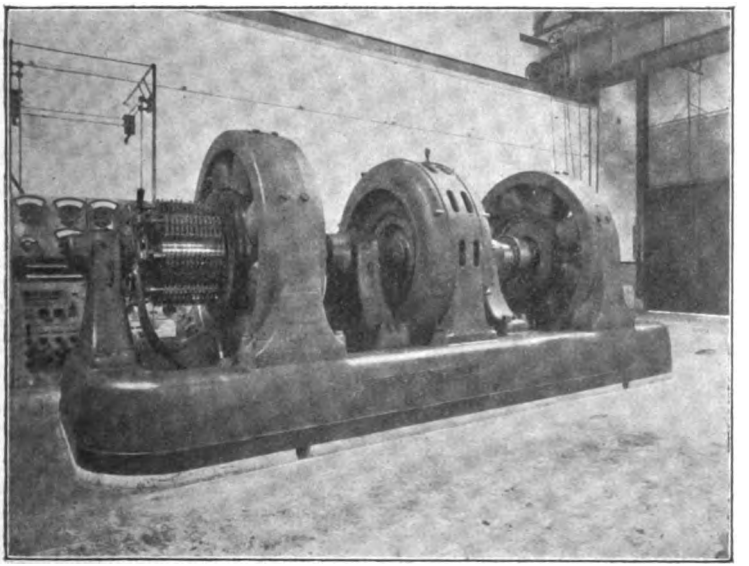

FIG. 14.

pearance of the oscillations, is usually about 45 seconds, during which the field strengths of the generators and motors are rapidly equalized, and the load will be found to be perfectly divided between the two generators, the mechanical oscillations having resulted in the only stable equilibrium possible under the conditions.

EXCITERS.

Before the installing of the storage battery it was necessary to have some quick means of getting continuous current, to determine the polarity of the rotary converters and energize

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the fields of the synchronous motors in case of a shut-down on the power circuits, and for this purpose two exciter sets consisting of 30-H. P. induction motors direct-connected to 20-K. W. 125-volt continuous-current generators were installed. Since the installation of the battery, all the exciting current is taken from it during the period of heavy load, for two reasons; first, to reduce the peak load; second, to automatically maintain an almost constant power factor of 98 per cent. leading, on the total load of the plant, due to the Edison load increasing (and bus bar pressure increasing correspondingly) simultaneously with the other station load and thus giving increased C. E. M. F. in the motors.

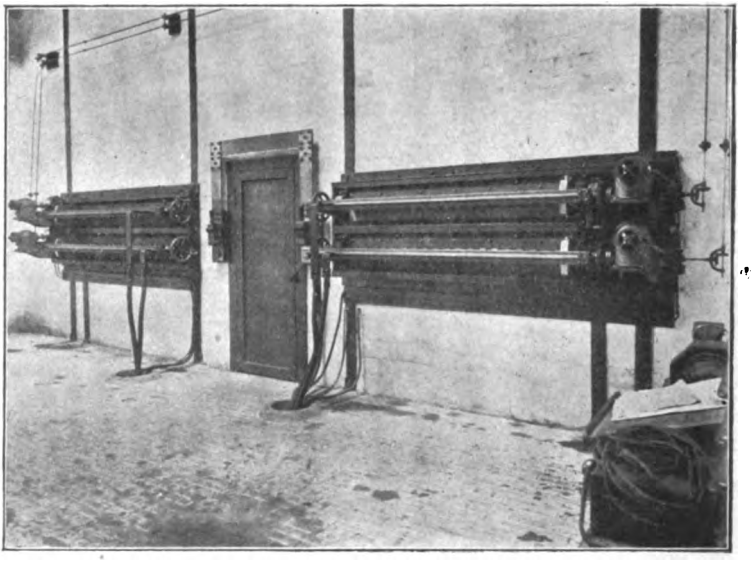

FIG. 15.

EDISON SYSTEM.

There are evidently two ways of converting three-phase 25-cycle current into 120 to 150-volt continuous current, one being by means of transformers with rotary converters, and the other with motor generator sets.

A comparison of the net efficiency of both systems for 200-K. W. units is given in the following table, the rotary including in its circuit some form of regulators capable of varying the voltage 25 per cent.:

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	Motor Generator.	Transformers and Rotaries.	Difference.
Full load.....	87.40	89.87	2.47
Three-quarter load..	85.54	88.70	3.16
Half load.....	81.42	84.90	3.48

Owing to the additional regulating apparatus necessary with the rotaries, the first cost in either case is practically the same.

From the above efficiencies, rotaries would seem to be indicated as the best choice, but in an extensive power transmission scheme where nearly 50 per cent. of the load is used for railroad purposes, and the generators have a comparatively poor inherent regulation to enable them to withstand safely severe short circuits on the lines, rotaries have had to be abandoned for this service,

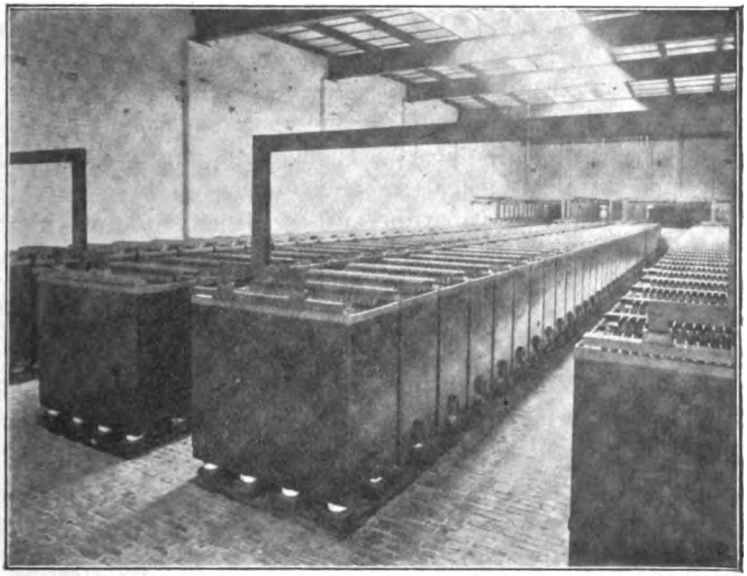

FIG. 16.

every fluctuation of the line potential being reproduced on the direct current side. Two 100 K.W. rotaries were installed, but additions have been made to the system only in motor generator sets, two of which are installed, the first of which is a direct connected set consisting of a 425 K.W. motor coupled to two 200 K.W. generators, [Fig. 14], having a very wide range of voltage to permit of charging the battery direct without the intermediary of a booster; the second, now being installed, is an 850 K.W. motor direct coupled to two 400 K.W. generators.

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A 150 K.W. booster set consisting of a synchronous motor coupled to two direct current boosters is used for charging purposes, and for carrying long feeders. The storage battery has a capacity for one and a half hours of 6000 amperes at 150 volts, [Fig. 16], there being 75 cells on each side of the system with two 20 point end all switches [Fig. 15], on each side to give control of the pressure under varying load.

A peculiar point observed is that a motor generator set and rotaries operating in multiple on the direct current side, tend to regulate one another, with varying speed, for constant potential. The rotary being practically independent of speed; a fall of speed or frequency on a transmission system having a large amount of inductance reduces the reactance, and a rise in speed increases the latter so that but for changes in the impressed voltage the rotary should give the best results on a system driven from water power in which the governors must of necessity be sluggish. The motor generator, on the other hand, is independent of changes in impressed voltage, but sensitive, especially with undersaturated fields, to change of speed.

In concluding this paper the author wishes to express his obligations to the *American Electrician* for permission to use cuts; to Mr. P. F. Sellers of the Cataract Power and Conduit Co., for outline drawings, and to Mr. G. A. Harvey of the General Electric Co. for photographs.

Much matter, which could, under a strict construction of the title, have been put in has been left out, and matter which in the author's opinion is more interesting and practical substituted.

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DISCUSSION.

MR. GANO S. DUNN:—The portion of the paper referring to the use of rotary converters and motor generators was particularly interesting to me, because of some recent interest I have had in that matter. I notice on page 138, near the bottom, that after giving the different efficiencies of these two arrangements for transformation, Mr. Stott gives the difference in first cost as about 19 per cent. Now, two-phase rotary converters have an increased capacity over the corresponding direct current generator, and three-phase machines a still greater increase, and my figures have led me to believe that the difference in cost between motor generators and rotaries even on the two phase basis is greater than 19 per cent. I should like to ask Mr. Stott what was the mechanical arrangement of the motor generators on which that cost was figured. Was it simply a motor coupled to a generator, or were two armatures on one shaft supported by only two bearings instead of four, and were there any other features that would throw light on the small increase in cost relatively to the rotary converters?

MR. STOTT:—In reference to the small difference of cost, I should say that all this work is three-phase work, and that the price of rotaries include static transformers, whereas the price of motor generators does not.

After leaving the transformer house at Niagara Falls everything is three-phase from there onwards. The difference of cost was taken from actual figures, and I do not know exactly what to ascribe it to unless that the speed of the rotary converter was comparatively low, and the comparison probably would have come out more even, or rather a greater difference, had the speeds been more alike; that is to say, the speed of the rotary converter, as I remember, was lower than that of the motor generator set.

MR. CALVIN W. RICE:—I would like to ask if any data have been obtained in these experiments on the watts lost per duct foot in multiple duct construction?

MR. STOTT:—In reference to Mr. Rice's question, that is not one that is taken up in this paper, and I cannot answer that question off-hand, but a great number of experiments were carried on at Niagara Falls, the results of which I have not with me to-night, but I know, speaking from memory, it came out that when the ducts were in a greater number than 25, and were all filled with cables, that is to say, three-conductor three-phase cables, that it became almost impossible to get rid of the heat without some special means of ventilation. The test was made on conduits as actually laid with wires pulled through them, and run up to a temperature corresponding to what the dissipation of heat would have been with a three-conductor 2200-volt cable, and for that reason instead of supplying a large factory near the

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power house at 2200 volts it was decided on the strength of those experiments to supply them at 11,000 volts to get rid of this loss of energy in the cables. I am sorry I have not got the figures.

MR. RICE:—I would like to ask if in practical operation you run paper cables at a higher temperature than you do rubber?

MR. STOTT:—The paper cables have only just been put in. They only went into operation about a month ago, so that they have not been forced at all.

MR. C. P. STEINMETZ:—I would like to ask Mr. Stott whether with the types of switches employed in the different stations, the open air long break switch, and the oil switch, he has noticed any difference in the action of those switches on the circuit, that is, whether sometimes one switch is more liable to cause rupture of the cable than the other, if such rupture occurs at all.

MR. STOTT:—I do not believe that there has been enough difference in the behavior of these switches to really be noticeable; that is to say, these interruptions to the cables have usually happened during the time the cable was in service, and not at the time of the interruption of the circuit. There is one point we noticed in cables breaking down. that the breakdowns almost invariably came from one to three days after an interruption. That is to say, the current had been thrown on that cable at full pressure, and we were afraid that some resonant effects had taken place, because an examination of the statistics of break-downs showed in almost every case that the break-downs occurred from one to three days of the time when the cables had been out of service and had been suddenly put into service at full pressure.

MR. ELIAS E. RIES:—Mr. Stott states on page 138 that the largest user of power in Buffalo is the International Traction Company, which receives a total of 7,000 horse power in five sub-stations, which is first transformed from 11,000 volts to 375 volts, and then converted in rotary converters to 600 volts direct current, for supplying continuous-current railway motors. I would like to ask Mr. Stott whether or not the International Traction Company has ever attempted to use the alternating current for the direct operation of motors on cars instead of first converting it into direct current.

MR. STOTT:—No; that attempt has never been made.

MR. RIES:—At our last meeting Mr. Hammer gave us a description of several electric railway installations in Europe in which the motors were operated by alternating currents, and it would be interesting, I believe, to the members present to hear of some tests made in this country with that object in view. Perhaps, our friend Mr. Steinmetz, might be able to enlighten us on that subject.

MR. STEINMETZ:—I can do that very well, because I have made very many tests on the use of three-phase motors on railroad

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cars. The first tests were made in 1894, running a trolley car around the factory yard, and we have run the car many times since, and tried various types of motors on our experimental railroad track, and have satisfied ourselves entirely that with the three-phase motor on a car you can get a rapid acceleration, you can get any starting torque you want, you can do anything you want to do, but the motor is in its electrical and mechanical character, essentially a shunt motor. It has a torque proportional to the current, and independent of the speed at constant field excitation. That is to say, if you want to start you require at the moment of starting the same current for a given torque as you require when running at full speed, and the rest of the power corresponding to reduced speed is merely wasted in the rheostat. Shunt motors, continuous current, have been tried a number of times in electric railroad service, and have always failed, and that was the reason why the three-phase railroad motor has not been introduced. It is decidedly inferior in starting, and in running at low speed, and in acceleration, to the continuous current series motor. Now, there is undoubtedly a considerable advantage in the induction motor for a railroad car, because you can eliminate the rotary converter and the substations, and can install stationary transformer stations. It has the disadvantage that you need two trolleys. There is in existence a double trolley road in the United States, and claimed to be very satisfactory, but I do not think that a second one has ever been built. You can imagine how beautiful it would be in the center of a city to run a double trolley system. The three-phase motor nevertheless might come in use going from city to city, because there you have no switches and crossings. You do not need to start and stop so frequently. The only trouble is these suburban roads always run into a city, and you do not want to dump the passengers at the outskirts of the city and have them wait for the next city car, as necessary if you changed to direct current and different motors there. That is one disadvantage of the three-phase motor.

Then the three-phase induction motor has a power factor. In railway service you could not run a thirty-second of an inch air-gap between the rotary and the stationary member of the motor. You have to have a little more generous air-gaps for mechanical reasons. The power factor is some 80 per cent. with the usual induction motor air-gap. You can imagine where that power factor goes to with a larger air-gap. That means so much more current over the trolley line, not only so much more current but lagging current, which causes so much more drop in the reactance of the line in addition to the resistance drop. In continuous current trolley lines we sometimes have enormous drops. If you have a heavy load on the end of a feeder, from 500 to 600 volts that you start out with, the voltage may go down even to 200 or 300 volts. Well, it means the cars go along slowly, but still they

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go, and they give any torque you want in starting. With the induction motor, the torque is proportional to the square of the voltage. Hence, if you run the induction motor trolley line at 600 volts average potential, and the voltage is 300, the car will not start. You get over that to a certain extent by raising the voltage on the trolley. But then you have the deviation from standard practice. Everybody knows what the 550-volt trolley does, and nobody knows what the 3,000-volt trolley will do, except on paper, and on experimental lines. All these difficulties and objections of special arrangements and new untried methods in practice have to be considered. Still the system would be introduced if there were any essential compensating advantages. Theoretically you can undoubtedly see some points wherein the three-phase road is really superior. Since I experimented in 1894, I thought, and all my friends agreed with me, that it would be very nice to install a three-phase railroad somewhere. So I and all other railroad engineers with whom I am acquainted have endeavored to find a place where we really have a reasonable excuse to install a three-phase railroad. Once we nearly had one, and at present we again see a chance where we might install one, where there is really a good reason for using it, but thus far I have not installed any. Taking all into consideration, the wide range of speed and power required in railroading, rather militates against induction motors, which give full efficiency only at full speed.

Still, there may be special cases, and I hope still to live long enough to find a few where induction motors are preferable. For instance, where you climb a grade running up the Rocky Mountains, one side up and the other down, or anything of that kind, where you can give uniform speed running down hill, running a little above synchronism, and therefore have the induction motor act as generator on the down grade; you have the advantage that you do not wear out the brakes. However, the experience of the Jungfrau Railroad, which, as you know, was built as a three-phase railroad, was not very favorable. They have very few cars running, and once in a while it happens that a car was running down, returning power, and no car going up to use the power, and the ultimate outcome was that they put in some remarkably complicated arrangements for electrically consuming the power. But then I fail to see what advantage a three-phase current has in this case.

It is true in Europe there are a number of three-phase railroads; but we cannot draw any analogy from that, for the railroad conditions are very different there. The rotary converter is absolutely unknown to European engineers. They have never found out what that thing is. Rotary converters are being rapidly introduced in Europe,—but the engineers there know nothing about them excepting that they believe they are no good. All the converters there are American made, or made at branch factories of American com-

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panies, and so where the power for a railroad has to be transmitted a long distance as polyphase current, the rotary converter being unknown, the Europeans have used three-phase motors on the car. Here in the States the rotary converter was installed and put into commercial service, in 1894, in the early days of long distance transmission, and became so familiar to everybody that when long distance transmission for railroads came into consideration, the ordinary standard continuous motor was used, and nobody was forced to get up a new system of railroad motors, which offered no compensating advantages, and so the three-phase railroad motor has not been introduced here, although I hope we might still see some experimental plants.

THE PRESIDENT:—Mr. Steinmetz' account was very interesting, but I think he is mistaken in one or two points. I do not think the Jungfrau railroad is a failure. When I visited it last summer I was told quite the contrary[1]; the part that is now in operation is paying excellent returns for the investment in that part. The company is, of course, not paying any dividends yet, because it is continuing the construction of the road. The constructors worked all the previous winter at it, and this year I believe they intend to work all summer, too. Concerning that device for running down hill which Mr. Steinmetz referred to as being very complicated, I would like to explain that it is used only as a safety device, so as to be able to run down hill in case the continuity of the trolley wires or contact with them, is broken. Moreover it is at present used only on one of the four locomotives as an experiment; with the system used on the others, if a car goes down hill and something happens at the power station or to the trolley lines, so that it could not send the power back into the trolley lines, it would have to descend with the aid of the brake-shoe, which is objectionable. It is to meet this emergency that this system of exciting with continuous current is used. Moreover, it is not complicated in the least; it is simply the addition of a very small continuous current dynamo, belted to one of the motors. In other respects the plant is exactly the same as before. It cannot be said therefore that it is a very serious complication.

Concerning rotary converters, Mr. Steinmetz was not correct in saying that they are absolutely unknown to European engineers. They are known and are used there, though much less frequently. The foreign engineers differ with us in estimating the relative advantages of the rotary converter and the motor generator. I saw a large rotary converter of German manufacture, installed in the large, new Berlin station, and the engineer who designed the installation said that if he had to do it over again he would install a motor-generator. That rotary converter was also of interest in that it could be regulated for vol-

[1] Since this discussion took place I have been informed by a Swiss electrical engineer, who is in a position to know, that this railroad will unquestionably be continued, and that the reports of its failure were started by those who wanted to buy a controlling interest in the stock.

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tage. It was coupled on the same shaft with what might be called an alternator which was excited by the continuous current. The alternating current, before it went into the rotary, passed through this alternator and by variously exciting the field, the alternating current could be boosted up, or lowered in voltage, and in that way the voltage of the continuous current could be regulated without passing it through a second commutator.

MR. RIES:—I would like to ask Mr. Steinmetz whether it is not mainly due to the fact that direct-current motors in this country are standardized and a regular article of manufacture, that progress in the development of alternating current railway motors is more backward here than it is abroad, rather than to the many alleged disadvantages of such motors which he has stated. We know that there are a great many losses and complications in the methods which are practiced at Buffalo, as Mr. Stott showed in his paper to-night, and wherever else the alternating-direct transmission system is installed. It has been the aim of electrical engineers to overcome those losses and to simplify the equipment so as to avoid the necessity of having so many intermediate transformations and so much attendance at rotary sub-stations, etc., which the static transformer would eliminate. I am under the impression, at least it has been so stated, that there is a lack of serious effort made here on the part of the larger manufacturing companies to avail themselves of the opportunities presented by the use of alternating current railway motors for purely selfish reasons, rather than owing to their few disadvantages. The question of double trolleys, etc.,—three-conductors, in the case of multiphase currents—would not be so serious a matter in large cities where the underground conduit is used; the track could be used as the third conductor very readily, and the other disadvantages mentioned are not deterrent. The question is whether or not the fact that direct current motors have become standardized, and are used so extensively on existing railway cars as to cause a reluctance on the part of manufacturing concerns to such a change, is not the principal reason that the United States is so far behind Europe in this respect.

MR. STEINMETZ:—There is undoubtedly in the relation between standard apparatus and special apparatus, a good deal of cause for the customer to fight shy of three-phase motors; but as far as the large manufacturing companies are concerned, there is no disinclination on their side against the three-phase induction motors on railroads. On the contrary there is a very great tendency toward that practice, and it has been pushed to a good extent. I am quite sure that the Westinghouse company has been trying, just as the company with which I am connected has for a number of years been trying, to install three-phase induction motors on railroads.

I may, for instance, state that an American company is at present installing a three-phase induction railroad in northern Italy, not

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in America. The Italians wanted three-phase, and so they got it. But if it were this country, I would not recommend three-phase. I do not see any reason, because continuous current could do just as well, and better; but this road is being built, and I am very glad of it. Another instance we had some years ago, where we wanted to build a three-phase railroad at cost price, and see it go. But at the last moment the customer put on the continuous current. If you come to the underground conduit, you must consider that even at 20-cycles, the ordinary iron rail offers against an alternating current an impedance which is from three to five times the ohmic resistance, which is not negligible. Still there is really no disinclination by American designing and consulting engineers, but all have been very favorably inclined to the three-phase induction motor for railroads, only there was no case in this country where it could be conscientiously recommended in preference to the continuous current motor.

Mr. Joseph Sachs:—I think the acceleration of the induction motor in this case is such that we have ran ahead of the paper, and rather lost it in the background. I think that while we have all been most intensely interested in Mr. Steinmetz's discussion of the induction motor operation, we would be far more interested, if that were at all possible, to hear his discussion of the proposition that he had already mentioned, namely, the operation of protective devices on such systems as Mr. Stott has mentioned.

It seems to me that in the paper two peculiar forms of high potential protective circuit-opening devices are mentioned, and Mr. Steinmetz has already asked the question whether there was any difference in effect between the operation of a long drawn out arc circuit-opening device, and that of the quick circuit-opening device I think that is a question of intense interest to us all, and if Mr. Stott cannot give us detailed information thereon, that is, with relation to the effect of such circuit-opening devices, upon transmission and generating and translating machinery, perhaps Mr. Steinmetz can, or some of our other members may be able to do so. I should very much like to hear from Mr. Steinmetz his opinion, regarding, for instance, the relative supposed effect of long drawn out arc circuit-opening devices over those that operate instantaneously.

Mr. Steinmetz:—Regarding this question I may say that in the comparison of the long drawn out circuit-breaking device and the quick break—that the quick break is the air-switch, and not the oil switch. It is frequently assumed that if you draw a long arc in the air, that there is a slow break in the circuit. That is not the case. There is no break quicker than the break in open air. Metal vapor being of very low resistance can draw an arc two or three feet long, having a drop of not more than a few hundred volts. If in a high potential circuit you draw an arc of

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three or four feet, there is hardly any voltage across the arc, until it breaks. But the break is extremely quick. A friend of mine has made some very nice photographic investigations of the nature of the break in a high potential circuit, with capacity in shunt, and found that a short circuit across a high potential circuit ruptures itself with extreme rapidity.

When the oil switch was experimented with, I was very greatly afraid of it due to the quick break in the oil. Experience and a very careful investigation on high voltage circuits has shown that the break of the oil switch at very high voltage, three, five or ten thousand, is not a quick break. Liquid is practically incompressible, and therefore the gas bubble which is formed there stands under enormous pressure and holds the arc up to the next zero value of current. At the next zero value of current the liquid pressure blows out the arc. It seems to be the action of the oil switch to hold the circuit up to the next zero value and then extinguish it. So that other things being equal, the probability is that the open air break is more dangerous and destructive than the oil break. Now, I have no complete experimental record of that except that in investigations which were made incidentally on the same plant at Niagara Falls, described in the paper, with 5000 horse-power behind. When trying a number of different breaks I found that the only switch which would open the circuit with the resistance and inductance in series, which never gave a rise of voltage, was the oil switch. That is not quite conclusive, because all I had was ordinary resistance and inductance, but no capacity. The conditions may change as soon as capacity enters. But I know that in all inductive circuits, with negligible capacity, the air switch is more dangerous than the oil switch. It may then be assumed in the absence of more complete data that the oil switch is the safer one, even in other cases.

I have investigated that lately, and I shall at one of the next meetings read a paper on the theoretical investigations of these high voltage phenomena which may occur in transmission lines during a sudden change of circuit conditions, as closing the circuit on the lines, or opening it, or short circuiting it.

MR. CALVIN W. RICE:—I would like to ask if the speaker of the evening has followed the articles written by Mr. Mordey on "Cable Work," and has had any experience along the same lines.

MR. STOTT:—I do not know what articles you refer to.

MR. RICE:—The recent articles in *Engineering*, speaking about capacity in cables, and the amount of charging current.

MR. STOTT:—I have not read the articles in question.

MR. JOHN W. LIEB, JR.:—I would like to ask Mr. Stott in regard to the reference he makes to the cables, on page 136. He states that a rubber insulated cable with 9/32″ wall, 30 per cent. pure Para is perfectly reliable for 11,000 volts; but that 8/32″ insulation even with a higher percentage of pure Para is not.

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It seems to me that, with the difficulties which are encountered in the manufacture, and which can quite readily give rise to differences in thickness of dielectric greater than one-thirty-second, where such a deduction is drawn, it would seem rather to indicate that even the 9/32″ cable was perhaps insufficiently insulated, and that on the whole for such a high voltage there was not a sufficient margin of safety, and that the margin was sacrificed by the slight reduction of 1/32″. I should like to know whether that deduction was based on something else than the mere difference of 1/32″, because it seemed to me that with the variations that are likely to take place in manufacturing such a cable there ought to be a greater margin than one-thirty-second of an inch between an insulation thickness sufficient to secure perfect reliability, and one that is not. In this light I do not understand the conclusions arrived at by the author.

MR. STOTT:—With reference to these remarks, as stated in the paper, these are the general conclusions that we have been able to draw from the actual number of breakdowns during a period of three years. These cables have been used over three years, and were made by very reliable manufacturers, the best manufacturers probably there are in the United States, and we have had more breakdowns on that 8/32″, although it has been in a year less than the other two, and naturally we began to think that the puncture resistance was not so great with 8/32″ as it was with 9/32″, and there does seem to be a distinct difference, and that the 1/32″ makes a marked difference. These are from a record, very carefully kept, of all breakdowns. I am sorry that I cannot say whether it broke down to ground or between conductors, because after an 11,000-volts burn out there is not anything left to tell. But 1/32″ extra insulation seems to give very greatly increased reliability. That is, after the cable has been in use for a long time. By a long time I mean several months. There is another fact that possibly may have something to do with it, and that is whether 40 per cent. of pure Para is not too pure and deteriorates under pressure. Some experiments are being carried on that I know of as to the deterioration of insulation under a continued high pressure, and the loss of insulation, that is to say, the megohms as measured by the galvonometer, after a continuous application of high pressure, is very distinct. That is to say, there is a distinct fall in insulation as the test is continued. If at the end of ten days the insulation is 400 megohms, at the end of twenty days it will be down to perhaps half of that value and keep on decreasing. These experiments are not yet complete, but the tendency has been very marked in that direction, and apparently (from these experiments being carried on) the purer rubber is going that way faster than the less pure.

MR. CALVIN W. RICE:—I would like to ask if the dimensions of the cable are those in the specification or the dimensions

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observed by inspection of various lengths, and if 9/32″ means the least dimension that was observed in any of the product; also is the 30 per cent. cable made by one maker and the 40 per cent. made by another maker, and if there were tests made to determine whether there was exactly 30 per cent. or 40 per cent.

MR. STOTT:—In reply to these questions, the thickness of the wall was quite carefully measured, and these are the means of a great many measurements, so that it may be taken that these represent the mean thickness of the wall. As to the percentage of pure Para, that we have got to rely upon the manufacturer for. As you know, the analysis of rubber is an extremely difficult thing to perform, and you can get almost any result you like with those hydrocarbons.

MR. RICE:—I would like to ask if these breakdowns occurred mainly in the cable or in the joints, and as to the possibilities of mechanical injuries as a cause for the breakdowns, or was the cable so destroyed that you could not tell whether there was mechanical injury or not.

MR. STOTT:—The breakdowns in almost every case in the cable referred to occurred in the middle of the section, or at least ten feet from a manhole, and the result was such that you could not tell anything about it. It just blew the whole cable to pieces.

MR. H. D. REED:—The conditions are so great and varied with the rubber in cables that I should think it would be necessary to determine whether that 1/32″ was the cause of these cables breaking down, that is, if a thirty-second less, rather than the treatment of the rubber itself, was the cause. Now, there are a great many grades of pure Para rubber, and the age of the rubber has considerable to do with it, also the length of time that the rubber is dried and cured before it is compounded, and the cleanliness of the rubber is a feature that enters very materially into the manufacture of cables. Now, I would be inclined to think that an 8/32 wall of 40 per cent. rubber would be safer than 9/32 of 30 per cent. rubber. From the experience I have had with cables, especially after a lapse of time, 40 per cent. rubber will be very much more durable than the 30 per cent. compound.

MR. SACHS:—I am not familiar with the cable practice and transmission through cables, but it would seem to me, and it probably seemed to a great many others this evening, that the difference between 8/32 and 9/32 of an inch of insulation on a high potential cable is very small. The tendency to-day in engineering practice is to make everything "fool proof," and I think it also is in a great many cases necessary to make it mechanically and also electrically "fool proof." I should say if 8/32″ of insulation on a high potential cable were bad, that 9/32″ were almost equally bad, and if trouble was experienced with the 9/32″, I should add one or two more thirty-seconds of rubber, and get a little additional factor of safety.

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MR. STOTT:—I would reply to Mr. Sachs' remark—there is another factor besides the factor of safety that enters into the question, and that is the matter of cost. A cable of 1/32″ extra insulation would probably send up the price 25 cents a foot.

MR. SACHS:—Quite true. But I should think that the deterioration would in time affect the 9/32″ just as much as it previously did the 8/32″, that it was simply a question of time before the 9/32″ broke down, and if you added a few more thirty-seconds it would take a little more time to break down, and thus you might continue the life of the cable. That is simply my opinion of the matter. As I said, I am entirely unfamiliar with the practice.

[Adjourned.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 26, 1901.

The 153rd meeting was held this date at 12 West 31st Street, and was called to order by President Hering, at 8:20 P. M.

THE SECRETARY:—At the meeting of the Executive Committee this afternoon, the following Associate Members were elected:

Name	Address	Endorsed by
ANDERSON, DOUGLAS SMITH	Professor of Electricity and Electrical Engineering, University of Mississippi, University, Miss.	Brown Ayres. Harris J. Ryan. Edw. L. Nichols.
BREWSTER, WALTER SCOTT	Electrician, Standard Underground Cable Co., 205 Market St., Perth Amboy, N. J.	H. W. Fisher. A. J. Rowland. R A. Fessenden.
BURNETT, JAMES AUBREY	Draftsman and Designer, Royal Electric Co., 94 Queen St., residence, 19 Shuter Street, Montreal, P. Q.	P. G. Gossler. R B. Owens. Ernst J. Berg.
CLARK, FARLEY GRANGER	Electrician in charge 96th St. Power Station, Metropolitan St. Ry. Co.. 96th St. and 1st Ave., residence, 439 Manhattan Ave., New York City.	W. N. Ryerson. P. Torchio. J. J. Mahoney.
CLOUGH, DWIGHT EDWARD	Electrician, Buffalo and Lockport Railway, Lockport, N. Y.	P. Eskil Berg. H. S. Webb. C. E. Gifford.
GILLIS, HARRY ALEXANDER	General Superintendent, Richmond Locomotive Works, Richmond, Va.	Gano S. Dunn. Wm. S. Aldrich. Thos. V. Bolan.
HAUBRICH, ALEX. MICHAEL	Electrical Engineer, Central Union Telephone Co., 1309 Ashland Block, Chicago, Ill.	H. S. Carhart. S. G. Mc Meen. B. J. Arnold.
HODGES, WILLIAM LEMMON	Asst. Engineer, The Keystone Telephone Co., 750 Drexel Bldg., residence; 3453 Woodlawn Ave., Philadelphia.	Louis Duncan. J. J. Carty. Henry Floy.

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HOPTON, WALTER EDWIN	General Superintendent Cincinnati Edison Electric Co., Cincinnati, O.	A. N. Mansfield. F. E. Idell. W. K. Archbold.
KILGOUR, MARTIN HAMILTON	Borough Electrical Engineer, Corporation Electric Works, 2 Church Street, Cheltenham, England.	W. H. Preece. C.H.Wordingham W. M. Mordey.
LEEDS, MORRIS EVANS	Managing Member of the firm, Morris E. Leeds & Co., 259 North Broad St., residence, 3221 N. 17th St., Philadelphia, Pa.	Edwin J. Houston Chas. J. Reed. Carl Hering.
MO BERTY, FRANK R.	Telephone Engineer, Western Electric Co., Chicago, Ill., residence, Evanston, Ill	T. D. Lockwood. I. H. Farnham. F. A. Pickernell.
MONRATH, GUSTAVE	Engineer and Superintendent, Grace & Hyde Engineering Co., residence, 26 E. 42d St., New York City.	C. G. Armstrong. H. B. Coho. M. Coster.
ROBERTSON, JAS. MCCALLUM	Superintendent, Power Department, The Royal Electric Co., Montreal, P. Q.	Norman Ross. P. G. Gossler. Ralph D.Mershon
THORNTON, KENNETH BUCHANAN	Superintendent Line Department, The Royal Electric Co., residence 840 Dorchester Street, Montreal, P. Q.	P. G. Gossler. H. R. Leyden. R. M. Wilson.

Total 15.

The following Associate Members were transferred to full Membership.

Approved by Board of Examiners, March 18th, 1901.

BUCK, HAROLD WINTHROP Electrical Engineer, Niagara Falls Power Co., 170 Buffalo Avenue, Niagara Falls.

BURGESS, CHARLES FREDERICK Assistant Professor, Electrical Engineering, University of Wisconsin, 609 Lake Street, Madison, Wis.

FISHER, HENRY WRIGHT Electrician and Director of Electricity and Chemical Laboratories, The Standard Underground Cable Co., Pittsburg, Pa.

HAFER, GEORGE, JR. General Superintendent and Electrical Engineer, Cincinnati Gas Co., Electric Department, Cincinnati, O.

KENAN, WILLIAM RAND, JR. Traders' Paper Co., Lockport, N. Y.

MURPHY, JOHN Superintendent, Power Houses, The Ottawa Electric Co., Ottawa, Ont.

SPRINGER, FRANK WESLEY Assistant Professor Electrical Engineering, University of Minnesota, Minneapolis, Minn.

The President announced that the Council had prepared and now submitted in writing an amendment to the Constitution, which would be brought up for consideration at the Annual Meeting May 21st.

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DR. SAMUEL SHELDON:—Mr. President, before those amendments are read, I would like to make a motion—inasmuch as we have two papers for this evening—that Mr. Dunn make a digest of the amendments and present to us the radical changes, omitting those parts which are common to both Constitutions. [Carried.]

Mr. Dunn having outlined the proposed changes in the Constitution, it was voted that the new Constitution, as revised by the Committee, be printed and distributed to the membership before the next meeting.

Prof. Harris J. Ryan then presented the following paper on "The Transformer for Measuring Large Direct Currents."

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A paper read at the 153d Meeting of the American Institute of Electrical Engineers, New York, April 26th, 1901. President Hering in the Chair.

THE TRANSFORMER FOR MEASURING LARGE DIRECT CURRENTS.

BY HARRIS J. RYAN.

In operating practice, the use of the transformer for the measurement of large alternating currents is now widely adopted. No similar operating use of the transformer can be made for direct currents. This paper, however, presents *a method for large direct current calibrations* that employs the transformer for comparing the values of large and small currents in terms of the ratio of transformation and the reading of the instrument used for measuring the small current. The method is based upon the following principle:

Where two direct current carrying coils of similar dimensions are placed side by side and linked with a closed laminated iron core of low reluctance, the permeability of this core for alternating magnetic flux will be a maximum when the ampere turns of the two coils are equal and opposite.

The test for maximum permeability to alternating flux may be applied in various ways. I have found the one given by the diagram of Fig. 1 to work very well. In this diagram A-1 is an ammeter that has been recently standardized by reference to the Clark cell and a Reichsanstalt resistance. A convenient range for this instrument is from 0 to 25 amperes. With reference to A-1, the heavy direct current shunt and milli-voltmeter type of ammeter is to be calibrated, checked or adjusted. The ampere turns produced by the small current drawn through the secondary coil, B, mounted on the core, C C, and the ammeter, A-1, are to be balanced against the ampere turns produced by the large current through the single primary turn, A, and the

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ammeter, A-2. In circuit with A-1 and B there is a water rheostat conveniently arranged so that the current on this circuit may be smoothly yet quickly adjusted to any desired value. The auxiliary primary and secondary circuits, *a* and *b*, the two two-part commutators mounted and driven on the same shaft, and the galvanometer, G, are for the purpose of noting when the permeability to alternating flux of the core, C C, is a maximum, as the current in A-1 and B is changed to bring the ampere turns of B equal and opposite to those in A due to the large continuous current.

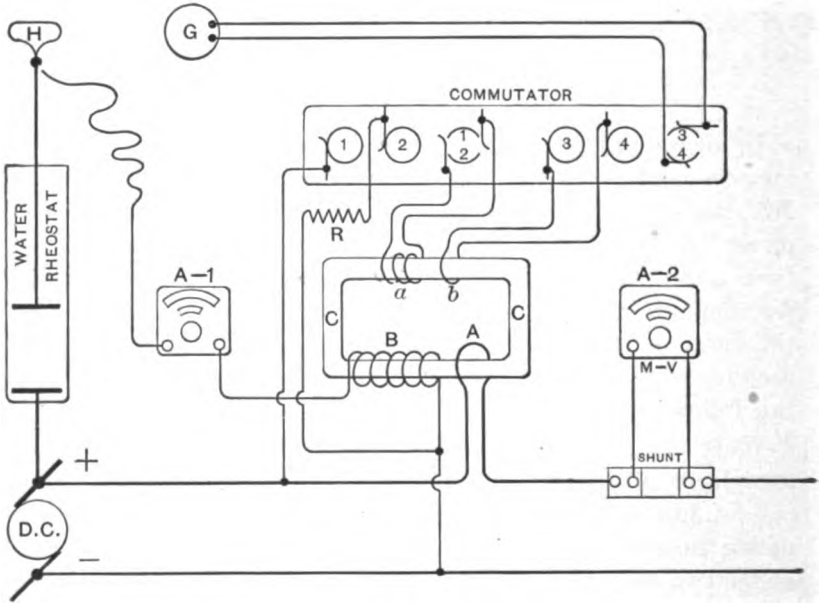

FIG. 1.

The alternating current through the primary, *a*, which provides the necessary small alternating M.M.F., is obtained by passing a direct current of one or two amperes from the large direct current source, D.C., through the controlling resistance, R, the revolving two-part commutator, 1-2, and as alternating current through the small auxiliary primary, *a*. The secondary, *b*, contains one turn which connects with alternating current through the revolving two-part commutator, 3-4, and with rectified current through the galvanometer, G. The two-part commutators are mounted and driven on the same shaft. The brushes of

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these commutators are set on diameters that are at right angles to one another. Thus *b* is definitely connected to the galvanometer, G, at each reversal of the current that occurs through *a*. In our trials of this method we drove the commutator shaft from a fan motor. The commutators can easily be made light enough to be driven by clockwork if so desired.

At a given commutator speed and current running through *a*, the galvanometer, G, will give a maximum deflection when there are no currents in A and B, or when the ampere turns of those coils are equal and opposite. To determine the current in A-2 in terms of A-1, an observer at the galvanometer adjusts the current through A-1 and B by means of the water rheostat until a maximum deflection is obtained at G, at which point the instru-

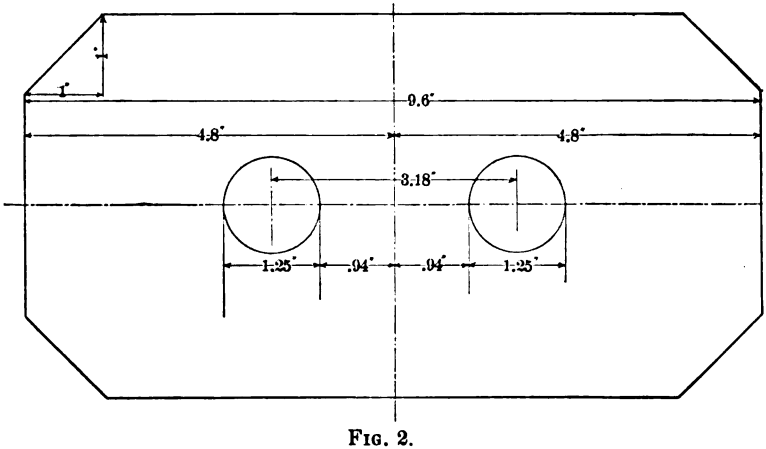

FIG. 2.

ments, A-1, and A-2 must be simultaneously read. The value of the current through A-2 is the current through A-1 multiplied by number of turns in B,—A having one turn.

TRIAL OF THE METHOD.

A transformer for this purpose was constructed having the following specifications and dimensions:

The Core.—The core was built of .016″ Apollo transformer japanned steel sheets. The shape and size of each sheet are given in Fig. 2. Total number of sheets, 117.

The Current Coils.—For convenience in checking the results, a ratio of transformation of unity was adopted, *i. e.*, the coils A and B as indicated in the diagram of Fig. 1, consisted each of 15 turns of No. 10, B & S. G.

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The Alternating Induction Coils.—The coil, *a*, contained 27 turns of No. 18 B. & S. G., and the coil, *b*, contained one turn.

The transformer was connected with testing circuits and facilities in all respects as described in connection with Fig. 1. The galvanometer used at G is a "Queen Portable" that gave a deflection of one small division per .0008 volt. It has a range of 15 small divisions, plus or minus.

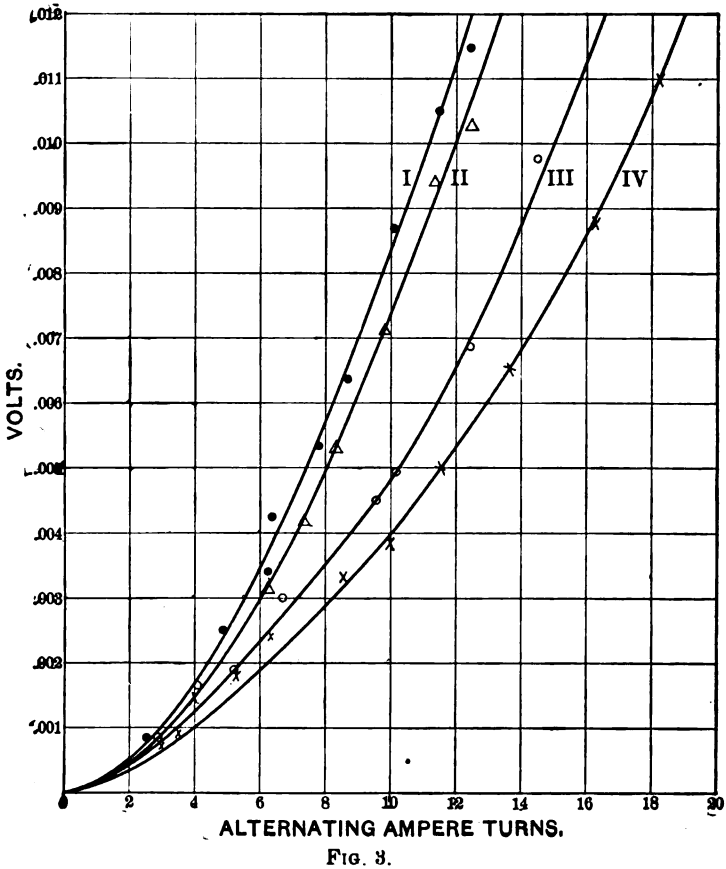

FIG. 3.

FIRST EXPERIMENT.

A series of observations was first made to determine the sensitiveness of the core to changes in permeability for alternating induction when subjected to direct current M.M.F'S. in either of the coils, A or B., under the action of various magnitudes of alternating M.M.F'S. The results of these observations are given by

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the curves in Fig. 3. For example, curve I was obtained by applying different values of alternating current through the coil, *a*, see Fig. 1, and at each value observing the reading of the galvanometer, G, when no current was passing through either current coil, A or B. Curve II was obtained in the same manner except that a small direct current was passing through *one* of the current coils, *i. e.*, either A or B. The amount of this current was

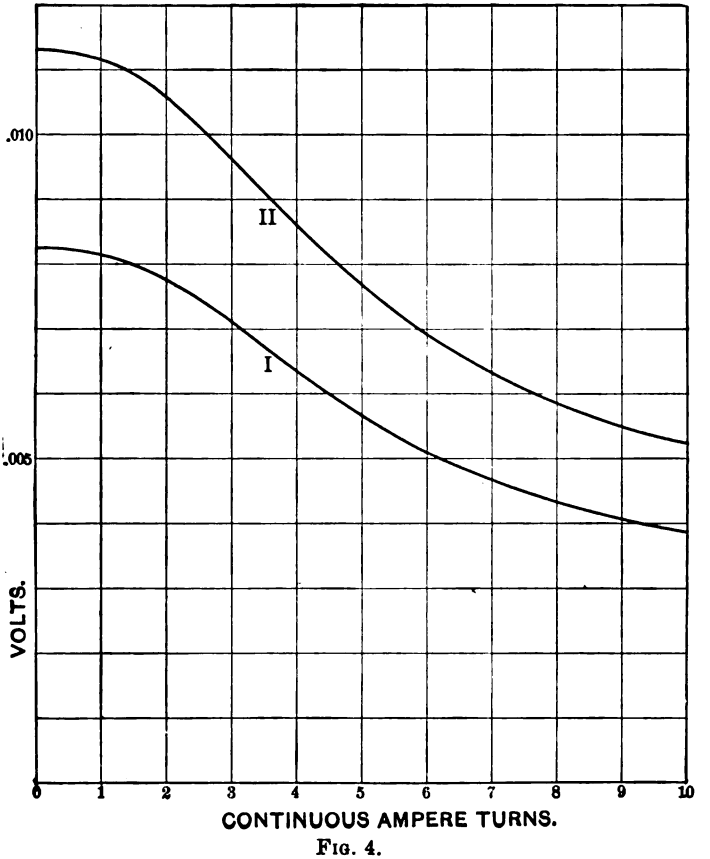

FIG. 4.

such as to produce in 15 turns a M.M.F. of 2.8 ampere turns. The remaining curves, III and IV were determined in the same manner for M.M.F's. in one of the current coils of 6.62 and 9.91 ampere turns.

An inspection of the curves enables one to determine the number of alternating ampere turns that should be applied as a minimum for observing when the continuous current in the coils

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A and B are equal; likewise approximately the accuracy obtainable with this method. Thus at 10 alternating ampere turns the volts obtained at G are read from each of the curves I, II, III and IV of Fig. 3. These values when plotted with their corresponding continuous current ampere turns maintained in one of the current coils, form the curve, I, drawn in Fig. 4. In the same figure, curve II is correspondingly drawn for 12 ampere turns.

An inspection of these curves in Fig. 4 shows that the galvanometer deflection remains near the maximum regardless of the amount of continuous M.M.F. applied from 0 to 1 ampere turn. In addition to this the galvanometer required a change of .0004 volts to enable the observer to be readily certain that such change was due to passing beyond the ampere turn balance in the current coils and not due to slight speed variations. From curve II in Fig. 4 it is seen then that a difference of two ampere turns must exist between the M.M.F.'s of the current coils before an ample falling off in the galvanometer, G, deflection has occurred to be easily caught by the observer. Where the transformer of the above dimensions is worked to 100 ampere turns in each of the coils, A and B, an error of $\pm 2.\%$ would thus be made; at 500 ampere turns the error would be $\pm .4\%$; and at 1000 ampere turns $\pm .2\%$. The transformer here tried could not be worked beyond 200 ampere turns without undue heating. *With care in manipulation these errors may be largely eliminated.* We found that the best results in this respect are obtained when the observer at G changes the balancing current uniformly in one direction until he notes that the balance has been passed; he then changes the current in the opposite direction until the balance is again passed as shown in the first slight diminution in the reflection at G. The observer then holds the water rheostat in the midway position and announces the balance, when the observers at A-1 and A-2 read. The curves I and II in Fig. 4 also show that there is no advantage in using more than 12 alternating ampere turns in this particular transformer through the coil, *a*.

Second Experiment.

In this experiment a trial was made to determine identical currents in the coils A and B. Two Weston 15-ampere ammeters were used for A-1 and A-2. They were carefully compared with one another by passing current through them in series.

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A continuous current was set up through A, and current was turned on through B, and adjusted until G indicated a maximum at which moment A-1 and A-2 were read. The following tables give the observations made in this manner by various observers as stated, who manipulated the water rheostat, and announced the balance observed at G. Each observer was instructed to pass the balance in both directions by increasing and decreasing the balancing current, and then to set the water rheostat in the middle position, when announcing the balance. The current source, D.C., Fig. 1, was from a 125-volt, 50 K.W. Edison dynamo that was driven by hand controlled water power and engaged upon an additional fluctuating laboratory load. All current values were for this reason more or less constantly on the move:

Mr. Hoxie, observer at G:

	A—1.	A—2.
No. 1	9.95	9.93
2	9.80	9.77
3	9.75	9.75
4	9.70	9.74
5	9.75	9.84
Average	9.79	9.81

Mr. Norris, observer at G:

	A—1.	A—2.
No. 1	9.60	9.62
2	10.48	10.48
3	10.55	10.57
4	10.54	10.49
5	10.56	10.34
Average	10.35	10.30

Mr. Cowing, observer at G:

	A—1.	A—2.
No. 1	10.40	10.34
2	10.41	10.40
3	10.40	10.40
4	10.44	10.45
5	10.41	10.43
Average	10.41	10.40

It is seen that the errors thus made range from plus two-tenths of one per cent. to minus five-tenths of one per cent.

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Third Experiment.

A number of trials were made to determine the effect of external magnetic forces upon the point at which the balance would be indicated. A 1,000-ampere-turn coil was placed on the transformer core in a number of positions, and trials for a balance of the current in A and B were made, with the current "on" and "off" through the disturbing coil, and no perceptible effect was observed.

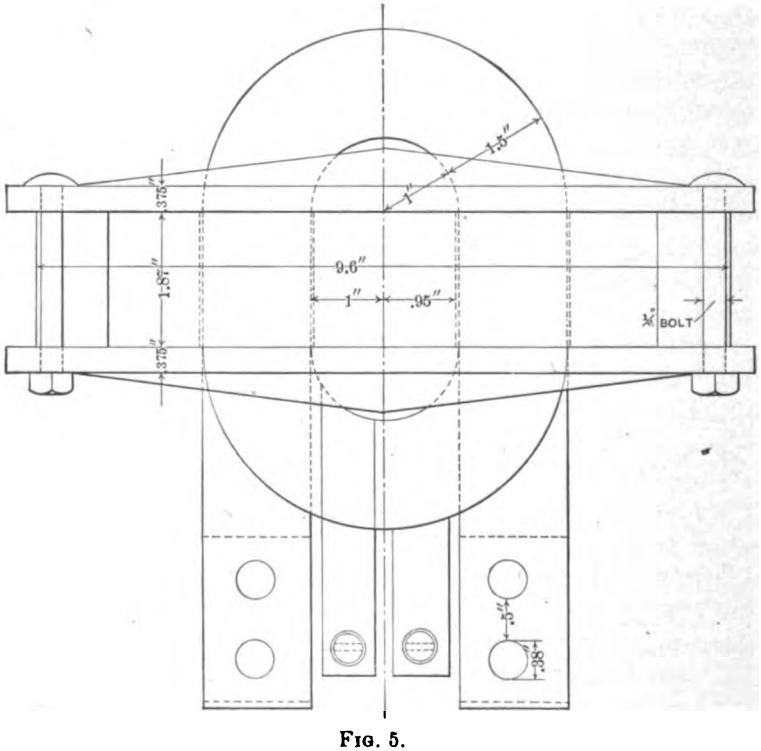

Fig. 5.

It was thus determined that errors due to external M. M. F's would not occur in the application of this method under all ordinary conditions that are present on switchboards for heavy currents.

This did not, however, determine that errors are not due to internal magnetic leakage, since in this experiment when the ratio of turns was unity, magnetic leakage was purposely eliminated by winding side by side the two conductors forming the

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two coils. Thus the coils were thoroughly interlaced and could not produce appreciable magnetic leakage.

It was necessary then to determine the error due to magnetic leakage which in the ordinary transformer gives rise to transformer self-induction. For this purpose I used a transformer that had been designed to work as an alternating current multiplier. It was intended to multiply the current range of a 25-ampere instrument 40 times, so that it could be used in a 1,000-ampere circuit. Transformers for such purpose do not have to approach perfection in the elimination of self-induction. The construction of this transformer is given in Figs. 5, 6, 7, 8 and 9. The construction details given in these figures are so complete that no further description is necessary.

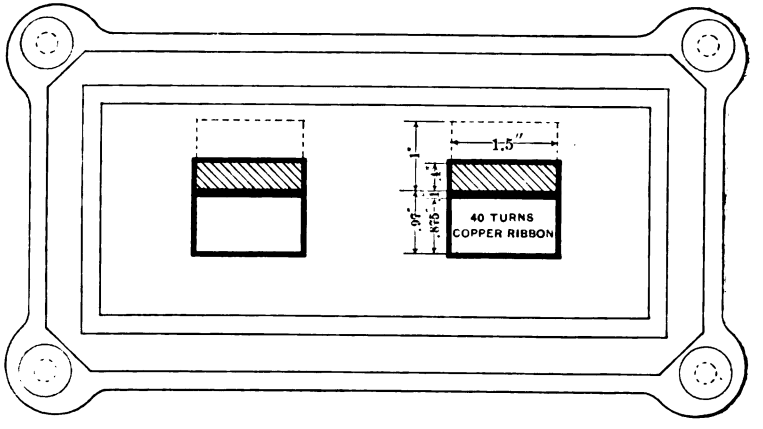

FIG. 6.

It should be noted that the peculiar construction of the 1,000-ampere single-turn coil where it passes through the core is for the purpose of lessening as much as possible, the primary and secondary conductor cross-sectional area that must be enveloped by the core. Thus the core reluctance is diminished to a minimum—a very desirable feature for an alternating current multiplier. This is accomplished by the loss of some additional E. M. F. through magnetic leakage or transformer self-induction—a point not important, as stated above, in current multipliers.

This transformer is well-suited for trial to determine the effect of internal magnetic leakage upon the accuracy of the direct-current transformer-balance. Currents up to 1,000 amperes were

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furnished from a 2-volt direct-current generator through the single-turn coil, and balancing current was supplied through the 40-turn coil from a 110-volt direct-current machine. The heavy current was measured by means of a British Board of Trade .0001-ohm, 1,000-ampere resistance standard and a Weston millivoltmeter that had been calibrated by reference to a Carhart-Clark cell.

The balancing current was measured in the same manner, using a .01-ohm Reichsanstalt low resistance standard and a millivoltmeter, also calibrated by reference to the standard cell. The

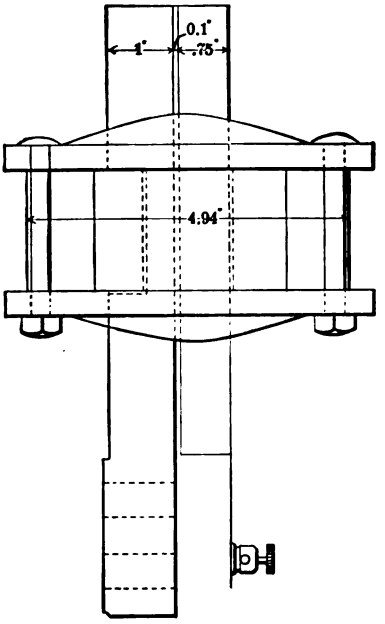

FIG. 7.

British and German resistance standards were compared with one another and found to be in agreement. The following results were obtained:

Amperes.	Ampere Turns.	Ratio.
40.6	40.2	1.010
157	154	1.020
500	476	1.051
648	621	1.044
1035	996	1.038

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Each set of the above results was obtained by taking the average of five balances and simultaneous sets of readings.

To those who are particularly concerned with all matters relating to the magnetic circuit, the column of ratios will be very interesting when studied in connection with the dimensions of this transformer. Most persons, however, will care for no further comment on the meaning of these ratios than that *pronounced internal magnetic leakage will produce errors amounting to as much as five per cent.*

A study of these results taken in connection with the construction of the transformer brought out the manner in which magnetic leakage produces this error. The error is due to the fact that the

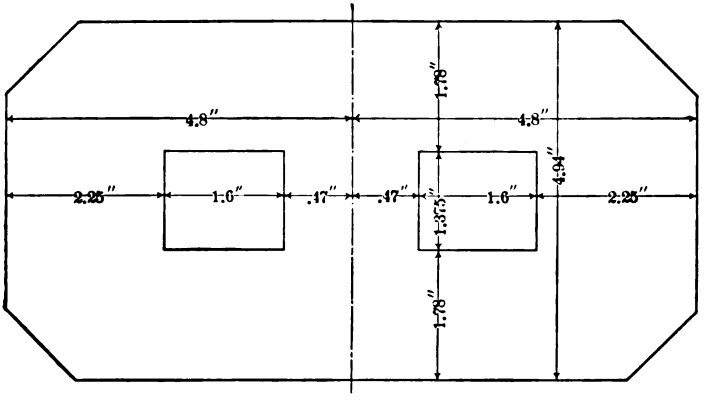

FIG. 8.

coil which occupies the larger cross-sectional space and which is the seat of the larger magnetic leakage behaves toward the one which occupies the smaller cross-sectional area as though it had more than its real number of ampere turns. The phenomena within the iron of the core where there is this unbalanced magnetic leakage may be analyzed, and the result obtained will show that the coil occupying the larger space will have apparently more ampere turns than the actual number present when the attempt to balance is made.

A type of transformer must therefore be selected which will avoid magnetic leakage as far as possible, and such leakage as does occur must be equal for each coil.

FORM OF TRANSFORMER ADOPTED.

The form of transformer that will avoid magnetic leakage

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errors, and which is conveniently applied under most practical conditions is illustrated in Fig. 10. Upon the laminated core are wound the ampere-turn balancing coil, and the few primary and

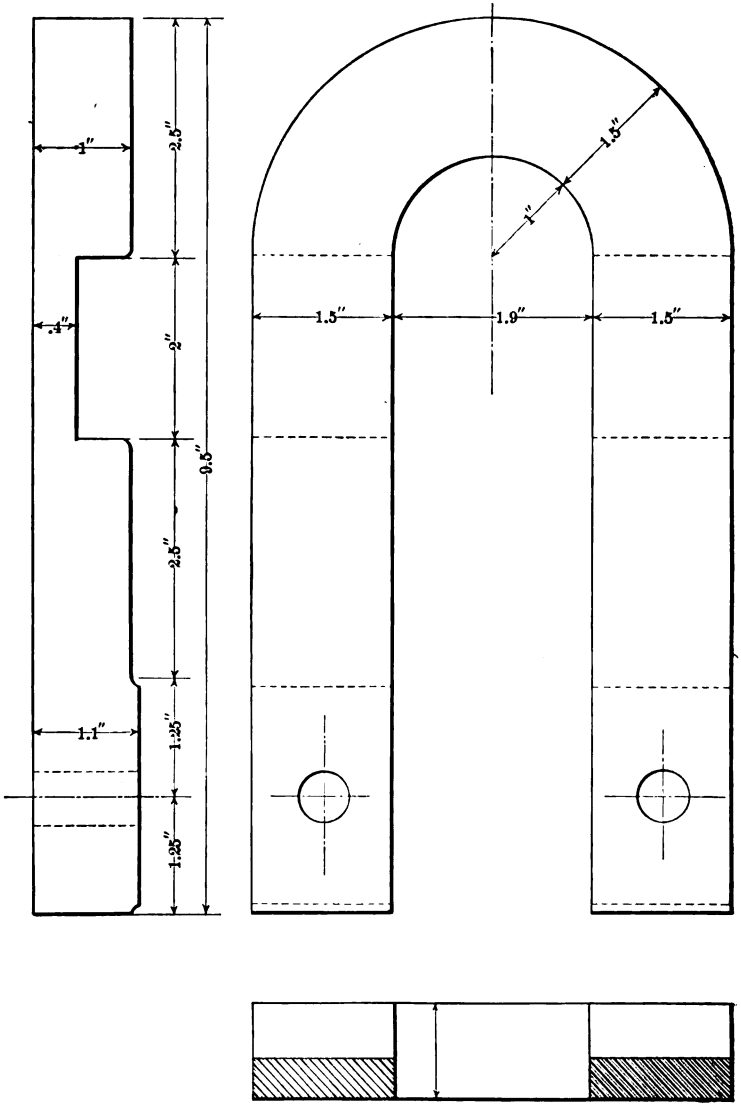

FIG. 9.

secondary turns for the alternating balance test. The core when wound is so shaped as to form a link, that makes an easy fit over

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the heavy conductor which carries the large current to be determined.

In Fig. 10 there is a single view of a transformer of this kind that Prof. J. O. Phelon constructed and assisted me to test.

The core is one-half inch square and one-quarter square inch in cross-section. The material in the laminations is continuous; no magnetic joints can be allowed in these cores. The laminations were cut from 14 mil Apollo electrical steel sheets.

The alternating primary contains 20 turns, and the secondary 10 turns.

The heavy direct current conductor measures $2\frac{5}{8}''$ by $\frac{9}{16}''$. The ampere turn coil is wound with 68 turns of No. 10 B. and S. cable.

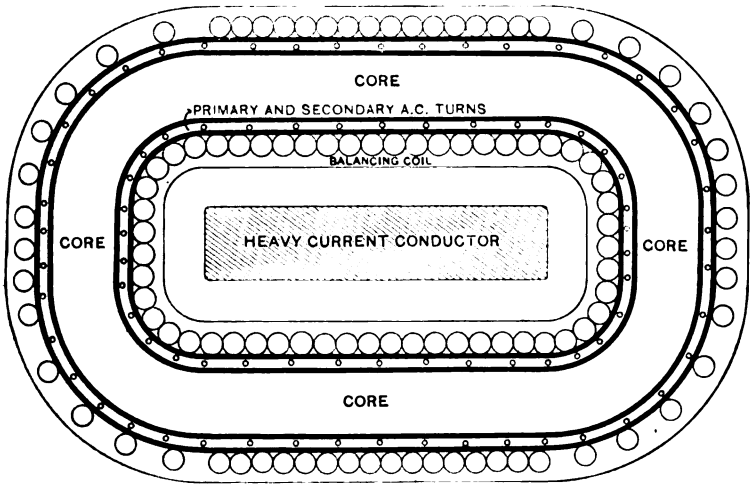

FIG. 10.

The mean length of the core is approximately 12 inches. The primary alternating current was supplied by 1.25 amperes of direct current passed through the two-part commutator. The alternating ampere turns applied to the core were, therefore, 25, or about two alternating ampere turns per inch of core. I usually drive the commutator from a small motor at a speed of 500 R.P.M.

In testing this transformer for error, the same instruments, standard and current sources were employed as when testing for the error due to magnetic leakage.

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The following results were obtained:

Amperes.	Ampere Turns.	Ratio.
238.7	238.7	1.0000
712.6	713.2	.9991

Each of the above set of values is the average of five sets of readings taken at five corresponding balances.

These excellent results were obtained by taking current from a fluctuating power source *i. e.*, the pointers on the ammeters suffered a steady drift to and fro so that the exact balance lasted for a moment only.

It must always be remembered that this is a zero method. Thus an error is introduced if the current either in the heavy or light circuit suffers a momentary and periodic fluctuation

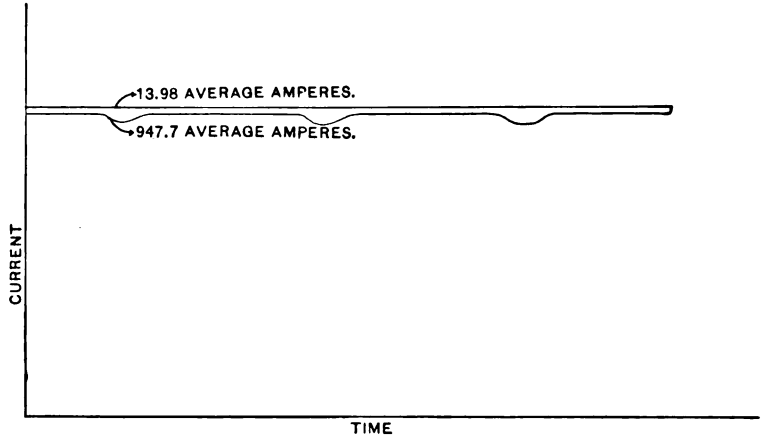

FIG. 11.

that is not common to both circuits. For example, when the current in the last test was increased to 950 amperes, trouble at the commutator of the 2-volt machine appeared. The brushes and commutator are too small for the delivery of so large a current. The pointer on the heavy current instrument showed a momentary periodic depression as indicated in Fig. 11. Since the balancing current had to be furnished at a higher pressure than two volts, it was taken from a separate 110-volt generator. The balancing current suffered no corresponding fluctuation in value. It is evident that the balance would be obtained at the higher value of the fluctuating heavy current. Since the instrument indicates the values of the average currents, it follows that the ampere turns in this instance will be too high. To study

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this source of error the current of 950 amperes was passed long enough to obtain five sets of readings. The following result is the average of this set:

Amperes.	Ampere Turns.	Ratio.
947.7	951.7	.9958.

The error due to this cause in this instance was, therefore, .4 per cent.

In practice, a case of this sort is not likely to be found. Where there are periodic and momentary fluctuations of the heavy current, the balancing current will be drawn from the same source, suffering practically the same fluctuations, thus eliminating the error. The above instance in our test is a highly aggravated case, and yet the error is within one half per cent.

In conclusion, I should state that I am well aware that this method of standardizing direct current instruments will look complicated to many. I would heartily recommend that they do not pass judgment upon it in this respect until they have given it a fair trial. The necessary apparatus is simple and inexpensive in each instance. It may be applied anywhere, and operates conveniently even with a variable power. The ampere links can be slipped over the circuits at the back of the switchboards once for all, or they may be slipped over the switch blades at the front, and instruments quickly and accurately checked up at any time by reference to a small instrument that is known to be correct, or which has recently been calibrated.

I wish to express my thanks to my colleagues, Mr. Henry H. Norris and Mr. George L. Hoxie, and to my students, Mr. H. E. Cowing and Mr. F. Martin, for their hearty and effective co-operation in conducting the experiments which resulted in the development of this method for the determination of large direct currents.

Department of Electrical Engineering,
Sibley College, Cornell University, April, 1901.

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Discussion.

The President:—Professor Ryan's ingenious arrangement is to me one of the most novel departures in measuring instruments that I have seen for some time. The idea of using a transformer for direct currents would not be likely to suggest itself to many, and the way in which he has solved the problem of thus applying a useful property of transformers, is certainly extremely ingenious.

The arrangement which he describes must naturally compete with the use of a standard low resistance and a milli-voltmeter. In his paper he has not brought out the advantages which his method will have over this older one, but I presume he will make this clear in the discussion. The paper is open for discussion.

Mr. George T. Hanchett:—I do not wish to be understood as criticizing, but rather asking for information. There are one or two points which I would like to have brought out. I understand, turning to Fig. 1, that the alternating current voltage used to excite the coil A is obtained by means, I presume, of a sleeve carrying two slip rings, which are respectively connected with the two halves of the two-part commutator adjacent. Now, if a dynamometer instrument were placed upon the terminals of the coil A, a certain deflection would be noticed. As the commutator began to turn, there would be times when the coil A was not connected with the circuit at all, for if the brushes were allowed to bridge between segments 1 and 2. it would constitute a short-circuit between the rings 1 and 2. This introduction of a series of short periods of no voltage on the coil A, would, it seems to me, materially affect the deflection of the dynamometer instrument connected across its terminals, and similarly affect the voltage obtained at the slip rings 3 and 4, and therefore the maximum deflection of the galvanometer or instrument G, would depend, not only on the permeability of the core C, but on the speed of the commutator, which should therefore be a constant quantity. Am I right in that understanding?

Professor Ryan:—If I may at this time answer the two points—first, as to the matter of bridging over the segments mentioned, it will be noted that the reversal of the direct current occurs at that point as described, in the first commutator. The galvanometer is connected firmly at that very instant, to the middle of the two sectors on the galvanometer commutator. It is just at the instant of the reversal of the direct current that you get electromotive force. There is therefore no trouble of the character which may be thought of as possibly occurring because of the short-circuiting during this short contact of the segments.

Then as to the speed of the commutator. It is true the electromotive force depends entirely on that speed. Nevertheless the observer at the water rheostat is in full touch with any variation of speed that may be occurring in the driving mechanism

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for these commutators; he is constantly running the water rheostat handle up and down, and he is entirely conscious of any change in speed that there may be on the part of the driving mechanism or the commutators, or on the part of the machinery that is developing the current. One cannot tell at the galvanometer G in this figure, and at the water rheostat, which cause it may be – either or both, for that matter, but you have entirely at your control the means for distinguishing between a maximum deflection that has come from your own act of adjustment of current, or from that which is due to the upward or downward drift of speed. That is a point, however, which actual experience with the method can only bring out, the conviction that this feature is all right.

MR. GANO S. DUNN:—On page 183, Professor Ryan says: "Where there are periodic and momentary fluctuations of the heavy current, the balancing current will be drawn from the same source, suffering practically the same fluctuations, thus eliminating the error." I do not know that I correctly understand that. It seems on reference to Fig. 1, that if the current passing through the instrument A–E, and going through the one heavy convolution around the little transformer, were to vary suddenly, that would not necessarily make the current in coil B vary equally, and consequently always balance it, because the current in coil B, as it is drawn here, appears to be taken across the poles of the generator D, C, in other words, in proportion to the voltage of the generator. Whereas the current in the coil A is current that is actually being drawn from the generator. The reason I ask this question is that if I understand the diagram right, this arrangement will not permit you to get increase of current, but only measurement of current at particular values, after which particular values you must adjust by hand the water rheostat H. If this is the case, its usefulness, while still exceedingly great, is limited more to calibration than to indication. I sympathize with Professor Ryan in regard to the costs of connecting up instruments for measuring large currents. It is only within the last few days, in connection with my work, that I had to authorize the expenditure first of a hundred dollars or so for the shunt, and a milli-voltmeter, and then nearly another hundred dollars for heavy copper castings and lugs and conductors and tips and bolts and things, in order to make these other parts useful, and some way to avoid that is very desirable. But from what I read in the paper, I do not understand that Professor Ryan intends his method to be used, for instance, where a set of observations are desired, under a condition of varying current, as in the case of dynamo testing, with the loads continually varying.

DR. SHELDON:—On page 169, in the second paragraph, the statement is made that "Where two direct current carrying coils of similar dimensions are placed side by side and linked with a closed laminated iron core of low reluctance the permeability of this core for alternating magnetic flux will be a maximum when

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the ampere turns of the two coils are equal and opposite." I should think that two coils of that character would exactly neutralize each other, and therefore there would be no magneto-motive force. If that were the case, the iron core would be exactly in a neutral condition. Now, if the iron core have the ordinary form of magnetization curve with the instep, the shin, the knee and the thigh, the permeability, which is equal to the flux density divided by the magnetizing force, would be a maximum not when there is a zero-flux, but when the iron is magnetized in either one direction or the other to a point somewhere near the knee of the curve. The indication on the electro-dynamometer, G, would be a maximum when there was an excess of ampere turns in either the large current coil or the low current coil; that is, at the exact neutral magnetic condition of the iron when the two magneto-forces are exactly equal and opposite, it would not give a maximum deflection in the electro-dynamometer.

PROFESSOR RYAN:—If I may answer these questions at this point it will facilitate my keeping them in mind during the discussion. As to the point, first of all, brought up by Mr. Dunn, I should be sorry if the paper were interpreted as though I meant to advocate that this method should be used for any other purpose than merely to calibrate instruments of the milli-voltmeter and shunt type already installed. If one must put those instruments into circuits for the measurement, presumably with laboratory facilities, they have been calibrated with reference to low resistance standards. But the method is intended more particularly for the calibration of switchboard instruments that are very excellent if one simply knows their constants or knows that they are right as to adjustment. It is a zero method, and Mr. Dunn is right in calling your attention to the fact that as such it can have no practical value for any other than calibrating purposes. It is to avoid the trouble that he spoke of, of having to make the expensive and troublesome heavy current connections for checking up instruments, that this method is to be used. Station instruments as now ordinarily made can very well be used for testing purposes, or for the ordinary purposes that come up as duty in the station, if one only knows, after they have been used for some time, what their character is as to adjustment—knows that they are right, or if they are off, how much they are off.

As to the point that Dr. Sheldon has just now brought forward with regard to magnetic action that goes on in the magnetic circuit, the very reason why we have adopted the alternating current test here, or rather permeability to alternating flux test, is in order that the trouble of all sorts that comes from the irregular portion of the B–H curve of iron will be eliminated. We thought of a great many plans by means of which we would not have to resort to the driving commutator and the alternating permeability test that we have finally adopted in that method, and found none so satisfactory as this. On thinking the matter over and remem-

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bering the nature of iron on the basis of the B–H curve, you will remember that permeability for reversal under magneto-motive force is a maximum so long as it is being done symmetrically about the axis. Anything that offsets it in regard to the zero line gives you a smaller range of travel for a given alternating effect plus a constant effect than you otherwise would obtain.

DR. ARTHUR E. KENNELLY:—The paper is interesting, if only for illustrating the modern tendency to turn to alternating currents when we encounter difficulties with direct currents. A short time ago we had so much difficulty in calibrating alternating apparatus that we used to have recourse to direct-current methods. Now the tables seem to have turned, and Professor Ryan goes to alternating currents in order to facilitate direct-current calibration.

The plan, as I understand it, is both interesting and ingenious, and consists in determining when there is zero-flux in a magnetic circuit operated upon by two continuous magneto-motive forces in opposite directions, one being from a single turn, carrying the powerful current to be measured, and the other being from many turns, carrying a small measured current. If I understand the matter correctly, and I have only just seen the paper, the alternating-current theory applies in the manner suggested by Professor Ryan just now, inasmuch as for cyclical alternations their amplitude is greatest, as he says, just at the zero point of flux in the magnetic circuit, although for direct-testing currents the criticism made by Dr. Sheldon would no doubt apply. There is one difficulty that occurs to me, and that is in regard to hysteresis. Suppose the big current through the single turn were applied first; that would magnetize the iron up to a certain extent. Then suppose the small current applied through the many turns. Although the two magneto-motive forces might be equal, and might have zero effect if turned on simultaneously, there might be, under the preceding conditions, a residual magnetism, due to hysteresis, and I suppose that unless that is wiped out by the testing alternating current the permeability would be affected thereby and the results vitiated. I suppose the alternating current must have sufficient magnitude to erase that residual magnetism. I see Professor Ryan indicates that my supposition is right.

It seems to me that the apparatus ought to be very useful for application in power stations and where elaborate apparatus cannot be availed of. But I suppose that Professor Ryan would not recommend this method to supersede, for laboratory testing, the calibration of ordinary apparatus.

PROFESSOR RYAN:—Dr. Kennelly is right in interpreting the view, at any rate, that I have with regard to the alternating current equalizing this hysteresis effect. The alternating magneto-motive force, whatever the difference may be, owing to the coming on at different instants of these two sets of direct magneto-motive forces will cause that difference to disappear. We have found it so. We have been very careful to examine that point. That is

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one great reason why we had to come to the use of the alternating magneto-motive force. By no other method, though we tried a great many, could we get over these very difficulties that Dr. Kennelly and Dr. Sheldon have spoken of.

I do not at all wish to put the method in competition with the refined method of adjusting an instrument, the Reichsantalt low resistant heavy current standard, and the Clark cell and the potentiometer, or a laboratory pattern of the milli-voltmeter, as made by an eminent maker of electrical instruments—not at all. But you cannot take your laboratory facilities with you into electric light and power stations, while, with these coils, you can consume very little time in applying the calibrating transformer method. I think it is well to remember that the laboratory methods, using the Reichsantalt standard, while splendid in the laboratory, will consume too much time and require one to use expensive connections for their application in the power house.

Mr. C. O. Mailloux:—I understand this method to be a zero method, which, however, differs from most zero methods in so far as the indicating instrument does not indicate zero reading when the zero point is reached, but indicates a maximum reading; that is to say, in this case when the point of zero flux in the core of the special transformer is reached, the galvanometer G gives the largest deflection. I would like to ask Professor Ryan, if this be the case, whether it would not be possible to make the transformer coil *b*, such that instead of having to step down from the coil *a*, it would step up; in other words, use a coil having a very large number of turns of fine wire, and then simply connect the terminal of that coil to an ordinary alternating current voltmeter. It seems to me that if instead of stepping down and getting a very delicate deflection, he were to step up and decrease the action, that he would then be able to get an action sufficiently great to show indications on the ordinary voltmeter such as are made for alternating current, and as the operation is one which is read by reference to the largest deflection, it seems to me that he would be able to get as good accuracy by that means as by the use of the very delicate milli-voltmeter or of the galvanometer G.

Professor Ryan:—In reply to the point brought up by Mr. Mailloux, we adopted this plan for the reason that there is some practical value, I think, in being able to use one of the milli-voltmeters of the same type that is used for ammeters, that one applies this method ordinarily to, to calibrate. That is, however, but one reason, and rather an unimportant one, I think. The most important factor determining this way of applying the balance test, or alternating permeability balance test, has been that we must not introduce too much activity of an alternating character there, or by mutual induction there will be interference. The method will not have the same integrity that it has with the smaller alternating activity of flux densities and periodicity that

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you can so easily make use of by applying the direct current instrument to test for balance through the two-part commutator.

MR. HANCHETT:—Would it be possible to open the magnetic circuit, and introduce therein a D'Arsonval coil neutralizing any residual magnetism, if such occurs, by means of an alternating current coil wound on the same core? A D'Arsonval coil, if a voltage were applied to it, would deflect if there were any flux, and would remain at zero if there were zero flux.

PROFESSOR RYAN:—We began with those models, and had to come to this arrangement. We had that one and a number of other models modified a good bit from the one that has just been brought up, and met with no success. I do not mean to say that final success could not be obtained that way, but we were not able to make progress, and further discussion of the matter as to why not, would involve a number of wee little things that made our experience with the method in attempting to use those models rather a discouraging one for the time being.

MR. TOWNSEND WOLCOTT:—Mr. President, I would like to ask Professor Ryan one question in regard to the maximum. How rapidly does the permeability vary in the neighborhood of the maximum value; in other words, how accurately can the maximum point be determined? Most maxima occur where the differential coefficient of the function is zero, and the rate of change is usually very small in the immediate neighborhood of a maximum, on both sides, and the maximum is consequently difficult to locate accurately by measurement.

PROFESSOR RYAN:—In reply to that matter, I may state that you will find, any of you, in trying the method, that the maximum is very crisply defined. I mean by that, however, that it is defined within such narrow limits in the balancing coil, that the errors of determination are within those that we care anything about for engineering purposes, namely, a quarter of one per cent.

THE PRESIDENT:—I would like to ask Professor Ryan if he found that it made any difference whether the current to be measured is brought from a lower value up to the desired reading, or is brought down to that reading; that is, is the effect of a previous increase or decrease in the main current noticeable? In other words, does the alternating current entirely wipe out a residual magnetic effect that might have been induced by an increasing as distinguished from a decreasing current?

PROFESSOR RYAN:—We have found that it does, with the proportions that are advised in this paper. You are not able to distinguish as to the value obtained, whether you come to the balance by bringing the balancing current there from a lower value to a higher value, and thus to the balancing point, or by first going up and then dropping down to it; the same values are obtained either way.

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THE PRESIDENT:—That is, because you use an alternating current in the testing apparatus?

PROFESSOR RYAN:—Yes.

THE PRESIDENT:—It would probably not be the case if the arrangement just suggested by Mr. Hanchett was used, because there would probably be an after effect of the current.

PROFESSOR RYAN:—There would be that, and the insertion of a gap in the core induces many troubles.

THE PRESIDENT:—Do you not have to be very careful about the magnetic leakage? In other words, do not the windings of the two direct currents have to be in very close proximity to each other and absolutely symmetrical with each other? Because it seems to me that if there is magnetic leakage between them, due to those strongly magnetizing currents, it would produce quite an error in the reading.

PROFESSOR RYAN:—The matter just referred to we went into quite carefully, and find that by adopting the type of transformer, as stated in the paper, and which I illustrated by means of a lantern slide, and disposing of it in the manner there shown, one is not then called on to incur any risk in this respect whatsoever, according to our experience. In other words, the disposition of the balancing coil and its core, with reference to the conductor carrying the heavy current, must be such as to produce a local field on the part of the one coil through the core that is not pronouncedly different from the local field that is produced by the other conductor or coil. Now for the core that passes around the conductor, with the balancing coil mounted upon it, going entirely around that core, and giving to the core and the balancing coil thereon wound, an outline that corresponds to the conductor cross-section, one incurs no risk of error in this respect whatsoever, according to our studies. The case, for example, that we had on the screen, that same coil which we there used for calibrating the 4,000-ampere ammeter, we used likewise on a 750-ampere circuit, where the conductor carrying the current was very much smaller. We placed that at the center of the rectangular core. Immediately on one side was the equalizer blade of the same switch carrying current. That, however, would not produce error, because any stray field that it sets up is in common with the magneto-motive force action of the balancing coil and the main conductor that is carrying the heavy current that passes through the balancing coil. With that design of transformer that is here advised, whatever leakage defects there are, they occur in such a respect that there is no interference with the indication of the true balance. The balancing coil does not present in effect more ampere turn than the actual number that it possesses, nor does it present less.

There being no further discussion, the following paper by Professor F. W. Brady on "Electricity in Mountain Mines" was read by Dr. Sheldon for the author.

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A paper read at the 153d Meeting of the American Institute of Electrical Engineers, New York, April 20th, 1901. President Hering in the Chair.

ELECTRICITY IN MOUNTAIN MINES.

BY FRANK W. BRADY.

As the theories which are fundamental in the generation and transmission of electrical energy have been very largely represented in the proceedings of the INSTITUTE in papers of more or less heavy character, the writer has thought that it would not be out of place to present a descriptive article. The purpose is to give the particulars and details of a few plants illustrating the general conditions and difficulties to be encountered in making three different kinds of installations, a classification depending upon the location of the mines, viz., those reached only over burro trails, those by aerial wire rope tramways, and the ones having wagon roads of various grades and conditions.

In the Rocky Mountain district there are a large number of electric mining plants ranging from that of a single diamond prospecting drill to those operating a great variety of machinery and requiring several hundreds of horse power. Although there are some restrictions to its use, the application of electricity in such plants is ideal, in fact, any other style of operation is prohibitive. Wood, water and coal are not available in many cases, and the mines are located frequently on the face of precipitous cliffs, and inaccessible except over a trail or an aerial tramway. While this is true of those already equipped, there are other mines waiting for similar improvements, cases where it is necessary for some one to "Find out mens' want and need, and meet them there."

The use of electricity has greatly improved the methods of working the mines and gives a corresponding increase in their

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value. A large number now have electrically lighted tunnels and mine buildings, electric driven hoists, air compressors to operate drills and forges, pumps, drills, blowers and mills. Of course electricity in mining operations, like its applications in all other industries, has been a gradually progressing science, its present perfection being the outcome of many trials and failures, mistakes and disappointments.

Beautiful creations of the designer, the founders' art, and the machinists' pride have left the assembly room with cheers for "bon voyage," but alas never to perform a useful service, unless 'tis "mens' want and need" to increase the dump of some mine or add to the momentum of an avalanche of tin cans in the mountain gulches.

Imagine, if you can, a cast iron drum 4½x5 ft., weighing 3500 pounds, and made all in one piece, to be transported over a burro trail, places in which a tenderfoot would hesitate to tread! Such designs have a delightful car ride of more than 1000 miles only to find a final resting place two or three miles from the mine where intended to be used.

The first requirement in making such mining installations is to get reliable data of the capacity of the water power. Generally the plants installed far exceed the power available to drive them. The report of the constructing engineer should be very elaborate, not only regarding the water power, but also in regard to conditions in the mine, the methods of transportation, special requirements in design of apparatus, maximum weight of parts and dimensions, the topography of the district for pipe lines, transmission lines, etc. As mountain streams are so variable, it requires measurements for a period of several years to get any reliable basis to work on. From the very nature of the case, such installations are far from the base of supplies and in locations often where little or no mechanical or electrical work has ever been previously attempted. Even at best, an unlimited number of schemes and devices must be worked out on the spot to facilitate the transportation, construction and operation of the plant.

It must be understood that in making any legitimate installation the purchaser from his standpoint insists upon quality of apparatus and construction and certainty of operation, the plant filling the needs of the mine in all the particulars guaranteed before its adoption. On the other hand, the contractor wishes

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the plant erected at minimum cost, and to be promptly accepted and paid for.

The plant of the American Nettie Gold Mine, of Ouray, Colo. is a good example of an installation in which all the mine machinery and most of the materials for the transmission line were transported from the railway over a burro trail. The source of power for the plant is the Uncompahgre River, a dashing mountain stream fed by springs and heavy snows from a very large area of an intensely rugged range. There is a considerable variation in the volume of the flow of the stream, the lowest being in February and March, when there is the least thaw and the streams are frozen. The flow at this time was found to be 960 cubic feet per minute. The river also has a daily variation, being lowest about three o'clock A.M., and highest in the evening. The flow is also cut off temporarily at times by big snow slides which close the stream until it can melt through them.

The highest water is in early July, when the first hot days in this region bring down all the snow from the immediate foot hills. No measure was secured of this flood stage. A 30′ log dam, a penstock 18′ high x 6′ square, and 400′ of 4′x5′ flume with sand box and screens were erected in the winter during the lowest stage of water. Ten feet of the penstock was built of 2″x6″ plank laid flatwise in tar and spiked together; upper 8′ of 2″x4″. Four 1″ anchor bolts extended through the entire height. The pipe line was 1400 feet long and 30 inches in diameter and made of No. 14 B & S steel. These plates as received were 36″x96″, and weighed from 65 to 70 lbs. each. These were punched, rolled and riveted and six sheets put together, the horizontal seams being double, and the vertical ones single riveted and making sections 17½ feet long. These sections were then dipped in a hot bath of maltha and coal tar and thoroughly coated inside and out. Ten barrels of the compound were required for the job. After drying they were hauled to the grade and put together as follows: beginning at the wheel end the sections were united by a 6-inch telescope joint. The larger ends of the sections were expanded by sprinkling with gasoline oil and firing. This process also softened the compound and aided in making a tight joint. The sections were forced together by using a set of triple blocks on each side, having two men operating each set of blocks and a fifth man to guide the end of the pipe and at the same time jar it to a tight fit by using

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a sledge against a block of wood on the end of the pipe. As the line was straight, and the fall not over 75 feet, this style of joint proved very effective. The wheel opening being 24″, a reducing section was necessary at this end. A 14″ manhole and a hose connection were also placed in this section. The connection at the penstock was enlarged from 30 to 36 inches to allow an easy entrance for the water.

A 3-inch air valve was inserted in the pipe on the highest vertical bend. Most of the pipe was laid on an elevated grade. It crossed the stream from which the water was taken, and required two special bridges for this transfer. Practically the whole of the pipe was therefore subject to the extreme changes of temperature. Such a pipe should be kept full of water to prevent undue expansion and contraction. If not, there will be excessive leakage.

The building erected to house the machinery was a two-story frame structure 30′x32′, the second story being used as a residence for the operator. The plan was made to accommodate duplicate generators to be operated by a 20-inch double discharge Leffel turbine with horizontal shaft and friction clutch pulleys, 28″ diameter x 13″ face, one for each unit. The turbine with its two 12″x4′ draft tubes was set on foundations as directed by the makers.

The foundations for machinery and building were made of rock and cement. However, the "I" beams composing the longitudinal part of the frame were deflected sidewise by the water pressure, and it became necessary to bring them into line again by the use of jack-screws, and then to extend the concrete foundation to the top of the beams. The wheel was fitted with a Wood governor, which worked very well for small variations of load; but for large ones like that caused by the starting of a compressor, it was of no value in this plant. When such changes were to be made, the operator was notified by telephone, and hand regulation was applied to the wheel. Without this hand regulation, the incandescent lights would be destroyed when a heavy load was thrown off. The plant was operated continuously.

The switchboard was made of kiln dried maple, and arranged for the duplicate 60 K.W. 500-volt compound generators.

The line extended over a very rough section of country, and was rather difficult both to locate and to construct. There were several zigzags so as to cross the cliffs where it was possible for

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men to approach the route. Trees were used for poles wherever possible. Other poles were cut from the nearest timber, and rolled or dragged into position, and set in holes blasted from the rock by the use of dynamite. Heavy guys and double cross-arms were frequently used along the line. The wire, 000 B & S bare copper, was received on wooden spools in lengths of 1000 ft. (500 lbs.). It was desired to take about one-third of these coils to the mine and run them out from that end. As 500 lbs. was too heavy for one mule to carry, and as it was preferable not to cut the wire, they were transported as followed: The wooden spools were removed from the wire, and the coils separated into four parts with connecting links. Two of these were placed on the pack saddle of one mule, one on each side, so as to balance. The other two were similarly placed on a second mule, the animals being connected by the 10 or 15 ft. of wire between the two loads. The outfit could then move single file up the trail. At the mine the four sections were replaced on the spools, which served as reels when placed on a spindle anchored to a tree. The end of the wire was passed through a friction clutch made of two pieces of plank bolted together, and then guided down the route of the poles by several men. A second section was then spliced and soldered to the first, and the operation continued until 3000 ft. of wire was drawn out, 1500 ft. on each side. Other sections were then drawn out by men and horses from the various locations along the route, which could be most easily reached, for the total length of 4400 ft. The completed joints were made Western Union style and soldered by pouring the molten solder over them. The wire was laid up and drawn into position in the usual manner. Special railway insulators were used to anchor the wire on the tops of high bluffs. Care should be taken in such rough country to set the cross-arms on the poles so that the grooves of the insulators will be in line with the wire, also that such construction be made extra good and strong.

The mine consisted of a series of tunnels opening in the face of quartzite ledges on the mountain side at an elevation of about 9500 ft. These tunnels were connected by a network of excavations from which ore had been taken. The tunnels were of irregular size, varying from that of a rectangle less than 4x6 to very large rooms or cavities. The mine was practically dry, though some water accumulated in two or three places.

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The mine equipment besides incandescent lights in the tunnels and buildings was as follows: one 12″x12″ high altitude type of Norwalk compressor, a No. 4½ Baker blower, and a Lidgerwood hoist. The machines were housed in good sized rooms made of boards and corrugated iron. It is necessary to cover such machines with a tight and strong roof to prevent small pieces of rock from dropping into the working parts. A substantial room for each machine is advisable, which can be locked to prevent meddling by employes other than the ones directly in charge.

The compressor was set in an offset from the main tunnel about 1000 feet from the entrance, and near the work to be done. This method of location is important, as it saves power, cost of installation, and avoids loss by leakage of pipes. No. 0 B & S insulated wire was used in this tunnel. The compressor was operated by a 35 K.W. shunt motor geared on the same bed plate. The air receiver 30″ in diameter x 10′, was located about 20 feet from the compressor. The jackets of the air cylinders and the intercooler were supplied with water from two 735 gallon tanks located about 100 feet from the compressor. A centrifugal pump was driven by belt from the intermediate shaft of the machine, and forced the circulation of the water through suitable piping. From 10 to 18 gallons of water per minute were passed through the compressor, and kept it in fair condition. The speed of the compressor varied from 150 to 200 revolutions per minute, and when operating two Ingersoll-Sargent drills and furnishing blast for one forge at a pressure from 60 to 80 lbs., the motor required from 65 to 80 amperes at 450 to 475 volts.

The No. 4½ Baker blower was located about 200 feet in the tunnel in the "Y" formed by a branch. A 15″ galvanized iron pipe extended from the blower to near the head workings. The blower was operated by a 6 K W. shunt motor arranged with a reversing switch so that the smoke could be exhausted directly from the head of the mine without scattering it through the other tunnels. Also by this method fresh air could be sent directly to the miners, and the work carried on with the least interruption possible. The blower required 7 to 10 amperes at 475 volts.

The hoist was set up in a branch from the extreme inner end of the main tunnel some 300 feet from the compressor. It was of the Lidgerwood style, operated by a 25 K.W. series street car motor controlled in the same manner. It was arranged with a

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drum for 600 feet of $\frac{3}{8}$" wire rope in one layer. The shop test of the motor showed 1300 lbs. raised 600 feet per minute. The normal load was 700 lbs. at 600 feet per minute.

The wire in the tunnels was of heavy weather proof insulation tied to heavy porcelain insulators bolted to wooden pins which were driven into holes drilled in the quartzite roof and walls. The location of the holes for the insulator supports so as to have the wire clear all obstructions, was done by two men, each with a lighted candle. By holding a candle at one pin and the other a few feet ahead at such points as allowed the lights to be seen by both men, the proper places for the pins were rapidly located. There was a heavy condensation of moisture on the insulators and wire. This was effectively prevented by coating them with P & B paint.

One of the greatest troubles experienced in the operation of high altitude electrical plants is from lightning. Electrical storms are of very frequent occurrence, heavy discharges from the lines occurring sometimes during clear weather. The arresters used on this plant were of the General Electric Co. magnetic blow-out type. Four were placed at the mine, and two at the station. As the mine was a dry one, it was difficult to get a suitable ground at that end. A good sized basin was blasted out of the quartzite near the mouth of the tunnel, and this was filled with charcoal, and the arresters grounded to a copper plate placed in it. The basin was kept damp by water occasionally thrown in it.

The transportation of the station materials and machinery was done by wagons in the usual manner. The equipment for the mine had to be taken over a very steep, crooked and more or less dangerous trail. All apparatus had to be entirely dismantled. The small parts and attachments were packed in ore sacks and carried on burros. The next larger sizes such as bearings, small gears, pulleys, etc., were wrapped in sacks and loaded on mules. All pieces too heavy for mules or of such shape that they could not be balanced on the pack saddles, were moved on sleds. These sleds were made of 2" x 4" pine, from three to eight feet long, and having a width of 20 inches. A sled was used for each of the pieces such as armatures, fields, pole pieces, sections of bed plates, gears, cylinders, air receiver, etc., etc. Some of these pieces required the use of four horses in tandem to move them on the trail. In passing the zigzags, blocks and ropes with two

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horses pulling down hill, was found to be the most secure and rapid method. Several of the parts of the equipment required three men with the use of four horses, and a good supply of tackle, crowbars, etc., working about five days to move each one to the mine from the railway station, a distance of about 2½ miles. Only a few pieces received scratches and bruises, and only one piece jumped the trail, and this fortunately did not sustain serious injury.

A rough test was made of the station. While not strictly accurate, it may be of some value in planning such installations.

When the output of the generator was 85 amperes at 575 volts, the average velocity of the water in the tail race was 188 feet per minute. The tail race 6′ 7½″ wide, x 4′ deep, x 150′ long, was made of planks, and had a fall of $\frac{3}{16}$″ per foot. The water velocity as given was obtained by counting the time for light floats to travel about three-quarters of the length of the race. These floats were placed in the middle, and in various parts of the surface of the stream. The depth of the water for this load was from 9¾ to 10 inches.

The approximate cu. ft. per min. was then as follows:

$$\frac{79\frac{1}{2} \times 10 \times 188}{144} = 1033.$$

Elevation of standing water in the penstock 103′ above datum.
" " " lower end of draft tubes 26.2′.
Total head = 103 — 26.2 = 76.8′.
Friction loss in 30-in. pipe for 1037 cu. ft. per min. = 4.3′.
Effective head = 76.8 — 4.3 = 72.5′.

$$\text{H. P. of water} = \frac{1033 \times 62\frac{1}{2} \times 72.5}{1033} = 142.$$

$$\text{Electrical H. P. output} = \frac{85 \times 575}{746} = 65.5.$$

Velocity of water in tail race for friction of station plus 40 — 20 C. P. 3.6 watt lamps was 88.8′ per min., the depth 4″ = 19.6 cu. ft. per min.

H. P. of water for friction plus the 40 lamps =

$$\frac{19.6 \times 72\frac{1}{2} \times 62\frac{1}{2}}{330000} = 26.9.$$

A diamond drill outfit for the San Bernardo silver mine of San Bernardo, Colorado, presents an example of construction

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work where it is necessary to transport the machinery and materials over a wire rope tramway. The plant was also installed in midwinter when the country was buried in snow, many of the gulches being filled, and the tops of large trees covered from sight. The source of power is Trout Lake, a pretty pool of water near the summit of the range. The same source also furnished power for the Telluride high tension long distance transmission plant which has been described in the TRANSACTIONS[1]. A 6 K.W. 250-volt generator was installed in the concentrating mill and belted through a countershaft to one of the two turbine wheels which operated the mill. The wheels had no regulators, but operated the generator at near enough constant speed for all practical purposes for the work when the whole mill was running. But when operating the generator alone, the wheel was constantly racing with the change of load, and regulation was necessary, which was had by putting a friction brake on the shaft of the wheel to be operated by a hand lever.

The required 2500 feet of line was erected in most part on the towers of the tramway. That in the tunnel was fastened on porcelain insulators bolted to the framing timbers.

It was desired that no piece of the machinery should weigh over 250 lbs., but the designer did not entirely comply with this request. Fortunately no damage was caused by the extra weight of some pieces. The drill had to be entirely dismantled, and the parts packed in ore buckets, and dropped at the nearest point to the tunnel opening. From here they were rolled and dragged through the snow to the tunnel. The machine was set up for work some 740 feet within the tunnel. It is the testimony of those who have tried it, that there is some difference between the ease with which a complicated machine can be set up in a wet tunnel, and in the assembly room as conveniently arranged in the factory.

The drill was of 600 feet capacity, and its total weight with the rods about 5000 lbs. The dimensions were as follows: Length 9′, width 4′, height 6½′. The drill rod was operated by a 2 K.W. shunt motor, which required from 6 to 8 amperes at 240 volts for normal operation, and 10 to 12 amperes when choked up. A 2½″x4″ Gould triplex plunger pump furnished water under 40 to 60 lbs. pressure to the drill, this motor re-

1 TRANSACTIONS, vol. ix, 1892, p. 430.

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quiring about 10 amperes. The drill rods were $1\frac{3}{8}''$ outside diameter and for $\frac{3}{4}''$ core, and made in 8′ sections. The outfit was furnished with two bits set with eight 2-carat stones each, and with five blanks. The machine drilled from 7 to 10 feet per day of eight hours operation, and required a newly set bit each day.

As a representative plant reached by a wagon road, that of the New York and Chance mines of Creed, Colorado, may be given. This was not so difficult in some respects to construct as the one for the American Nettie mine. All the machinery was transported on wagons over a road constructed at great expense for the mining district. The power station is a frame building located on West Willow creek in the cañon behind Bachelor mountain about $1\frac{1}{2}$ miles from Creed. This town consists of a few frame buildings, the whole outfit appearing as if it had been driven like a wedge into the cañon until the two rows of houses had become so squeezed (the town was built under pressure) that they had to climb the mountain sides in order to leave a little space between them for the entrance of pack trains and the inhabitants. Amethyst is located a mile farther down, and has more room. The plat of the two towns resembles a fan, Creed being the handle.

The cañon begins an abrupt ascent at the base of Bachelor mountain, and the wagon road follows a steep and zigzag course to the mines, which are in the timber land near the top. Log foundations were used for the building and machinery. The equipment consisted of a 5′ Pelton wheel with two nozzles, 4″ shafting, and necessary pulleys to drive two generators. The governor was of the differential type operated by a small water motor. One multipolar 100 K.W. 500-volt direct current generator was installed with the necessary switchboard. The line, 5700 feet, was of 00 B. & S. wire with tree insulation. It followed a deep gulch and thence over a high and rocky cliff and across the timber lands above to an air shaft over one of the tunnels. At this point a Siemens lead-covered cable of 240,000 circular mils was attached and led down the shaft and through the tunnel 400 feet to a hoist. A compressor was located along the line about half way between the power house and the mine. For lightning protection there were the magnetic blow-out arresters at the station, and a strand of barbed wire on the tops of the poles the entire length of the line. This wire was grounded frequently to

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the water pipe and to plates set in the ground. The Rand compressor was driven by a 45 K.W. shunt motor belted to it. The hoist was equipped with a 35 H. P series motor with street car control. Such hoists are designed after the usual plans which have been approved in the construction of those operated by steam.

The dam was made of 6″x 6″ sawed timber about 30′ long x10′ high, x 6′ broad, the front and back being laid solid,the two parts joined by braces, and the space between filled with earth. The bottom was started in a trench cut in the rock, and the timber work filled with concrete for the first few feet. A plank spillway 2′ 10″ wide, x 8½′ long, x 18″ deep, carried the water to the penstock. The water pipe was of black iron, the upper half 22″ and the lower 16″ diameter. The total length of 2300 feet was made up of four different weights of iron. That at the wheel was No. 8 B. & S., the remaining fourths of 10, 12, and 14 B. & S. respectively. The 24′ sections complete with horizontal seams, double and vertical single riveted, bolted flanges, gaskets, etc., were shipped from Denver. The total head was 325 feet, and the effective pressure when operating was 145 lbs. per inch. The plant could be used only part of the year, as the stream was generally dry during the summer.

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Discussion.

Dr. N. S. Keith:—Mr. President, this paper is almost exactly familiar to me. It rehearses many of the trials which I have experienced in the mountains of California and of Colorado and in other countries. I have no criticism to make of it. I know gentlemen here, from their smiles, who work in cities, above ground, and underground only when in dry locations; where they have railroads, wagons, horses, their men who have had experience in handling the goods, cannot appreciate the difficulties which the engineer, especially the electrical mountain engineer, meets everywhere he goes. He goes into the highest mountains, 15,000 feet above the sea; he goes into the lowest depths, two or three thousand feet below the surface; he has water dripping upon him, which runs continuously in the locations where he is obliged to put such delicate apparatus, such we used to consider them, as the electric motor and the generator. I need not enlarge upon these facts, because they will become familiar to some of you who will be obliged, in carrying out the details of your profession, to go into such localities. There the electrical engineer will be called upon to exercise his common sense, his adaptability to the conditions over which he has no control whatever, but where he has to confine himself to circumstances which he cannot alter. I can add one instance which shows a variation in the methods of conveying electrical apparatus to the mine. There are three mentioned in this paper, one of which is by a wagon road, another is by mule trail, another by an ærial tramway. I have a fourth one: A plant which I erected in the Alps, in the mountains of northern Italy, in 1896. The last five kilometres of the route from England to the mine at Pestarina, at the foot of Monta Rosa, was only approachable by a trail for that distance. There were but two mules in the whole country, and they were used only in the summer time to carry tourists who desired to climb the mountains and go to the glacier at the foot of Monta Rosa, and some of them have crossed the Swiss border into Switzerland. Those mules could not be used for the carrying of freight; but there was a regular transportation line which consisted in using the backs of men and women. The heaviest piece of apparatus which I took in there weighed 2,000 pounds; that was an armature. It had to be constructed at the shops in England and taken in that shape. The field of the generator was made of laminated iron and was put together, and the coils slipped upon the legs of the magnet in place. The armature was carried by sixteen men under a peculiar arrangement of poles, so they could all carry at the same time. It was taken over five kilometres (3½ miles) in that way. There was another heavy piece of machinery, a large turbine, made in Switzerland, to be taken in that way. I have some photographs of the methods of transportation which were used in carrying that apparatus into the

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mountains. The power was to be transmitted for a distance of three miles, or so, down into the mine for the operation of pumps, pumping a direct column of 900 feet in height. One of the difficulties which should belong strictly to the mechanical engineer or the mining engineer, but which had to be met by the electrical engineer, was the one of properly regulating the pressure of the pump and the column of water which had to be raised. These were triple plunger pumps. The column of water is not a constantly flowing one; it comes partially to rest between the different movements of the plunger. Under such extraordinary pressures, the air that is in the water, and which is used ordinarily in the air chambers, so as to equalize these extraordinary variations in pressure, is absorbed by the water and we had to provide a pump by which we could pump air into the air chambers of the pump. In that matter I had to meet the ordinary everyday Cornish mining engineer, with his conceited ignorance. He had always operated a Cornish pump which lifted water a hundred feet, emptied into a vessel, and from that vessel lifted another hundred feet, and so on until it reached the surface, 900 feet above the source of water; he did not at all understand an air cylinder attached to a pump; he said it simply increased the amount of power needed. After a great deal of trouble I was enabled to put in the proper air cylinders. But when I left the country and returned to England, he removed those air chambers, with the result that the pump was broken, and at the same time some of the pipes were burst. I only mention this to show some of the difficulties which the electrical mining engineer has to encounter, and as an addition to the items of this papər.

MR. C. O. MAILLOUX:—I am not an old pioneer like Dr. Keith; I am only what is usually called, out West, a "tenderfoot;" yet I wish to state that even we Eastern tender-feet sometimes have occasion to visit the wild and wooly West and to have experiences. These experiences are usually valuable. I was visiting a large water power electric station in Southern California a couple of years ago, and after seeing the inside, I went outside to inspect the outer portion of the station, and incidentally to take a photograph of it. My guide, who was one of the station attendants, was very kind and freely explained everything to me, but he had forgotten to explain one important feature of the locality, which soon proved to be the most interesting. After examining the tail-race and noticing the features of interest in it, I tried to get away to a little greater distance from the building so that I could include a greater portion of the building in the picture when I saw my friend, who was perhaps ten feet away from me startle somewhat unexpectedly. I asked him what was the matter. He said: "Oh, it is nothing; it is only a rattle-snake." You can imagine my feelings. I did not have much interest in photography for the next few minutes. He quickly killed the rattle-snake, while I quickly got into the carriage and went back to the city.

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I have also had occasion to camp out twenty-five or thirty miles away from the nearest city or town with a party of civil, hydraulic and electrical engineers, investigating water-power sites, and I have heard the cayote and the mountain lion disport themselves during the night, and heard the bat flit about and make things interesting, together with innumerable bugs, mosquitoes, etc. These experiences in distant climes have impressed on my mind two things—first, the difficulties of transportation, which are very strongly put but not at all exaggerated in the paper, and, secondly, the necessity on the part of the electrical engineer designing an installation for use in those localities, of attending to what I have learned to designate the "fool-proof" features of the installation. With reference to the first point, I may cite an installation which I have in hand in Arizona, where the item of freight and cartage is fully 20 per cent. of the cost of the machinery, although there is little if any mountain climbing to be done, the cartage being mostly over relatively level desert lands. As to the second point, the engineer should take into consideration the character of the talent that is likely to be called upon to take charge of the installation after it is finished, and the matter assumes sometimes very important proportions, especially when the plant is one employing higher potentials for transmission to long distances, and where several generators are to be used together, especially, as is the case in lower California, where several stations located at different points all connect with the same transmission line. The manipulations incidental to the synchronizing of machines, coupling them electrically together, the regulation of the water-wheels and the regulation of the electrical machines, etc., are at best, operations which require a certain amount of intelligence; but when these have to be attended to by people whose general education is none too great, and whose specific education, electrical and technical, is a vanishing quantity, one realizes the importance of having the outfit so designed that it will require the least amount of thought and discretion on the part of the attendant. In other words, it is absolutely necessary that the outfit should be made "fool-proof," so that not only the attendant may not be able to do any damage to the installation, but even that he may not be able to do any damage to himself, for in many cases he might be able to do both. In discussing this matter with the engineers of a large company in connection with the Arizona installation aforesaid, I mentioned to him that the station equipment would likely be in charge or in care of a type of individual, who in Arizona, they call "zanjero," a Spanish term used in irrigated districts of the Southwest to designate the man who regulates the flow of water—a gateman, or dyke-man, so to speak; and he at once agreed that if the man's name is "spelled that way," it is certainly necessary to make the thing as simple and as fool-proof as possible.

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THE SECRETARY:—There appear to me still other and different lessons to be taught by a paper of this kind. In the first place, it appears to me that the difficulties that the writer speaks of at the outset are due to lack of engineering, either at one end or the other, or at both, and evidences of the negotiations being carried on by commercial men rather than engineers. One of the first things that an engineer should know is the location of the plant that he is about to install, and certainly if he could have a chance to see the views that are to be shown this evening he would obtain an idea of what it is necessary to provide against. It is the tendency of these pioneers and veterans to dwell upon the hardships that a young man will encounter in such places. I was once a tender-foot myself, and I know something about electricity and something about mountains and a very little about mines, and I have had some experience with mules. But my idea is that any of these young men who are brought up here in the city and graduate at colleges, if they are not equal to any of these emergencies that arise in cases of this kind, have mistaken their calling and should take up something like an Episcopal rectorship. As a young man with enthusiasm for his profession meets those difficulties he will grapple them, and his ability will grow as the difficulties increase. I have never yet seen a young man of that kind who would simply lie down and not carry a project through. It is all very well for Dr. Keith and Mr. Mailloux to stand here and tell what you have got to run up against, and it is very good advice, but I have seen a good many young men without experience, and there were in our party in British Columbia several of this class who had never handled an axe or never seen or certainly never packed a mule and never pulled an oar, who held their own against the half-breeds and woodsmen, and would tackle hardships that the others would not endure, certainly not without grumbling. This matter was brought to my mind the other day by a letter which was written to my nephew, who had applied for a position in the signaling department of a certain railroad. I will not undertake to read this through, but I want to give you an idea that it is important to these young men. Now, this young man is a son of my brother, the late Franklin Leonard Pope, and is of as good stuff as his father, and he cannot be disconcerted by any of these assertions about his not being equal to the emergency. The letter says: "Yours of the 17th at hand. My experience with the average college man is that when put on hard work of a physical nature he is a 'quitter,' not necessarily because he is naturally lazy, but because the manual labor is too hard for him. This is unfortunate, but nevertheless true." Well, all I have got to say about those quitters is that they have mistaken their calling. What an engineer wants to know is whether there is money enough to carry out the plans. There is another thing that he wants to know, and that is whether there has ever been a man in that mine. If there has ever been a man there he will undertake to

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put a plant there. He might not know before he went just how he was going to do it, but if he was an engineer and was given ample means to provide all possible facilities he would install the plant, and before he got through with it, it would work.

THE PRESIDENT:—Speaking about getting over difficulties in mines reminds me of a case that you may have heard of, in which a mine which descended into the side of a hill had water in it, which had to be pumped out. There was no water power anywhere in the neighborhood with which to do it, so a pipe was laid from the bottom of the mine up to its mouth and thence down the side of the hill to a point below the level of the water in the mine; a water power plant was placed at the lower end, which by means of electrical transmission operated a pump in the mine which pumped the water into that pipe. Thus the water in the mine furnished the power itself, the whole combination acting like a siphon would for less heights. It shows the flexibility of electrical transmission.

Lantern slides were then shown, giving the characteristic features of the country in which the described mines are located.

[Adjourned.]

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, May 21, 1901.

The 18th Annual Meeting was held this date and was called to order by President Hering, at 8:10 P.M., who appointed Messrs. Edward Caldwell and Douglas Burnett as Tellers, and William Maver, Jr. and George A. Hamilton as Proxy Committee.

THE SECRETARY:—At a meeting of the Executive Committee this afternoon, the following Associate Members were elected.

Name	Address	Endorsed by
BALL, HENRY PRICE	Electrical Engineer General Incandescent Arc Light Co., 572 First Av., New York, residence, 66 So. Parsons Ave., Flushing, L.I.	Luther Stieringer. Martin J. Insull. Samuel Insull.
BENTLEY, EDWARD M.	Patent Attorney and Expert, Temple Court, New York City.	C. P. Steinmetz. Albert G. Davis. Ernst J. Berg.
BLACK, ROBERT GIVEN	Supt. The Chambly Mfg. Co., Richelieu Village, P. Q.	R. B. Owens. R. D. Mershon. R. A. Ross.
BOLLES, FRANK G.	Manager Advance Dept., Bullock Elec. Mfg. Co., Norwood, Ohio.	E. G. Bernard. Wm. J. Hammer. W. D. Weaver.
BRADY, NICHOLAS F.	Treasurer, the Edison Illg. Co., 57 Duane St., New York City.	J. W. Lieb, Jr. C. W. Rice. W. S. Barstow.
BYRNES, EUGENE A.	Principal Examiner Electro-Chemistry and Metallurgy, U. S. Patent Office, Washington, D. C.	E. A. Sperry. F. L. Freeman. E. G. Acheson.
CUNNINGHAM, RICHARD H.	Demonstrator of Physiology, Columbia University, New York City.	E. G. Willyoung. F. W. Roller. T. C. Martin.
DASSORI, FREDERICK HUMBERT	Student, Polytechnic Institute, 250 Union St., Brooklyn, N. Y.	Samuel Sheldon. Ralph W. Pope. Wm. J. Hammer.

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DONALDSON, WM. W.	Electrical Engineer, The Gould Storage Battery Co., 25 W. 33d Street, New York City.	Frank B. Rae. C. T. Hutchinson T. C. Martin.
DRESSER, CHARLES A.	Superintendent, Kohler Bros., 1808 Fisher Building, Chicago, Ill.	C. G. Armstrong. William Goltz. F. B. Badt.
DROHAN, T. E.	Superintendent of Shops, Northern Elec. Mfg. Co. Madison, Wis.	A. P. Kennedy. D. F. Stakes. O. S. Lyford, Jr.
EDDY, HORACE T.	Instructor of Electrical Engineering, Union College, Schenectady, N. Y.	A. L. Rohrer. E. M. Hewlett C. P. Steinmetz.
ELLIOTT, ELMER G.	With Guggenheim Smelting Co., Perth Amboy, N. J.	Wm. A. Anthony W. G. Whitmore. J. C. Bennett.
FRASER, JAMES WM.	Demonstrator in Electrical Engineering, McGill University, Montreal.	R. B. Owens. L. A. Herdt. E. M. Archibald.
HAWKS, H. D.	Engineer with General Electric Co., Schenectady, N. Y.	W. I. Slichter. Ernst Berg. A. H. Armstrong.
HENRY, IRA WALTON	Cable Engineer The Safety Cable Co., 229 W. 28th Street, New York City.	R. W. Pope. A. E. Kennelly. Wm. Maver, Jr.
HERRICK, ALBERT B.	Consulting Electrical Engineer, 120 Liberty Street, N.Y., residence, Ridgewood, N. J.	H. W Blake. W. D. Weaver. T. C. Martin.
HESKETH, JOHN	Electrical Engineer, Queensland Government Post and Telegraph Dept., Brisbane, Queensland.	J. S. Fitzmaurice. W.G.T.Goodman. A. J. Hanson.
HEWITT, PETER COOPER	11 Lexington Ave., New York City.	G. H. Stockbridge C. A. Terry. T. C. Martin.
HOLTZER, CHAS. WM.	President Holtzer - Cabot Elec. Co., Brookline, Mass.	E P. Thompson. Wm. Stanley. G. W. Blodgett.
JENKS, ARTHUR PERKINS	General Electric Co., 44 Broad St., New York City.	A. L. Rohrer. H. G. Reist. T. C. Martin
KEBLER JOHN LEONARD	Vice - President Ward - Leonard Elec. Co., 606 W. 114th Street, New York City.	H. Laws Webb. H. W. Leonard. T. C Martin.
MARSH, CHAS. J.	General Manager, Eastern and Northeastern Sales Depts, Standard Underground Cable Co., 56 Liberty St., New York City.	J. W. Lieb, Jr. E. A. Leslie. G. L. Wiley.
MERRILL JOSEPH F.	Professor of Physics and Electrical Engineering, University of Utah, Salt Lake City, Utah.	B. B. Brackett. H. S. Carhart. C.T.Hutchinson.
MINTNER, LOUIS	Engineer Switchboard Dept., General Incandescent Arc Light Co., 572 First Av., N.Y.	Luther Stieringer. Martin J. Insull. Samuel Insull.
MURRAY THOS. E.	General Manager N. Y. Gas and E. L. H. & P. Co., 55 Duane Street, New York City.	J. W. Lieb, Jr. Calvin W. Rice. W. S. Barstow.
POIRIER, ALFRED E.	Manager N. Y. & N. J. Tel. Co., Jersey City, N. J., residence, 29 W. 21st St., N. Y. City.	R. W. Pope. G. A. Hamilton. F. M Pedersen

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POWELL, EDWIN BURNLEY	Meter Tester, Edison Electric Illuminating Co., 55 Duane St., New York City.	Calvin W. Rice. H. A. Lardner. M. B. Waterman.
REID, WILLIAM	Switchboard Engineer, N. W. Telephone Exchange Co., Tel. Bldg., Minneapolis, Minn.	G. D. Shepardson C. L. Pillsbury. J. C. Kelsey.
RICE, MARTIN P.	Chief of Publication Bureau, General Electric Co., Schenectady, N. Y.	C. P. Steinmetz. Eskil Berg. E. W. Rice, Jr.
ROGERS, NELSON	Electrician, with Peter Cooper Hewitt, Madison Square Garden Tower, New York City, residence, Mt. Vernon, N. Y.	Chas. A. Terry. A. J. Wurts. F. A. La Roche.
RYDER, M. P.	Supt. of Bronx Dist., N. Y. Gas and Electric L. H. & P. Co., 699 Union Ave., N. Y. City.	E. A. Leslie. Calvin W. Rice. W. F. Wells.
SAGE FREDERICK BRITTAN	Partner, F. B. Sage & Bro., 123 Liberty St., N. Y. City.	Townsend Wolcott G. T. Hanchett. C. E. Whitney.
SALTER, THOS. FITCH	Designer and Inspector of Drawings, Western Elec. Co., residence, 11 W. 18th St., N. Y.	G. F. Atwood. O. A. Bell. F. A. Muschenheim
SPELLMIRE, WALTER B.	District Engineer, Bullock Elec. Mfg. Co., 220 Broadway, New York City.	Thos. French, Jr. R. T. Lozier. W. M. Venable.
SPENCER, CHAS. J.	Electrical Engineer with N.Y.C. & H. R. R. R. Engineering Dept., Room 512 Grand Central Sta., New York City.	C. P. Steinmetz. J. H. Vail S. L. G. Knox.
TAYLOR, ALBERT	Manager New York Office, Electric Storage Battery Co., 100 Broadway, New York City.	Herbert Lloyd. Chas. Blizard. J. B. Entz.
WALKER, FRANK WILKES	Student in Electrical Engineering, McGill University, 26 Summerhill Ave., Montreal, P. Q.	R. B. Owens. R. W. Pope. L. A. Herdt.
WENGER, EDGAR I.	Graduate-Student in Electrical Engineering, McGill University, Montreal, residence, Ayton, Ontario.	R. T. Lozier. R. M. Wilson. R. B. Owens.
WHITNEY, WILLIS R.	Asst. Prof. Theoretical Chemistry, in charge of Electro-Chemical Research Laboratory, General Electric Co., Schenectady, N. Y.	C. P. Steinmetz. A. G Davis. E. W. Rice, Jr.

Total, 40.

THE PRESIDENT:—During the past year, there have been a number of new departures in the affairs of the INSTITUTE. Among the most important if not the most important, is one which I have the great pleasure of announcing to you to-night. One of our oldest members has recently purchased and presented to the INSTITUTE the very valuable library of Latimer Clark in London, which is the finest of all existing electrical libraries of the earlier works. I will ask the Secretary to read his letter which was sent to Council to-day, and which was followed by the formal acceptance of the library by Council in behalf of the INSTITUTE.

The Secretary read the following letter.

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To the Council and Members of the
American Institute of Electrical Engineers.

It is my privilege to be able to announce the completion of negotiations by which I have become the possessor of the very remarkable collection of electrical books of the late Mr. Latimer Clark of London.

My object in securing this collection was to present the books to our Institute and make it the custodian of the most complete electrical library in the world, as well as to stimulate such interest that the Institute may in time own a permanent home in New York.

The assurances received from those who have co-operated with me in this undertaking, that the collection is very complete and includes practically every known publication in the English language previous to 1886, on Magnetism, Electricity, Galvanism, the Lodestone, Mariner's Compass, etc., have been more than verified by my own examination of the books since their arrival in this country. There are among its 7,000 titles many books which are not to be found in either of the famous libraries with which it has been compared, and I find that there are even some of the very earliest examples of printing.

I have always been a strong believer in the principle that every professional man is under obligation to contribute in some way to the welfare of the profession in which he is engaged, and in obedience to this idea I now desire to present this library to you complete, reserving to myself only the photographs, autographs and such duplicate books as I may add to my own collection without detracting from the completeness of the library.

As an early contributor to the Institute and one of the original members of its Building Committee, I am interested in securing for it permanent headquarters and adding to its importance, dignity and strength. It is my desire that the Institute accept the library and through its Library Committee and a suitable Librarian administer it in such a way as to make it generally useful, and I hope that the possession of these books will add to the Institute's prestige.

I am inclined not to suggest rules for the management of the library, believing that those who are in charge from time to time are in the best position to know what is desirable, but in order to fix its general character, and secure its permanence, I condition the gift upon the acceptance by the Institute of the following provisions:

First.—The library to be kept insured against loss by fire as fully as it may be practicable to determine its value, and an annual appropriation of $1500 to be provided for its maintenance.

Second.—A complete catalogue raisonné to be published in the name of the Institute, reciting the conditions of gift and explaining the features of interest of each book for the convenience and information of members. This catalogue to be prepared at once and a bound copy of it to be placed in the hands of each member of the Institute.

Third.—The library to be in charge and control of a Library Board or Committee made up of members of the Institute and not more than one quarter of the whole number of members of this Committee to be allied with any one commercial or other interest.

Fourth.—The library to remain in New York City and to be a reference library, free to all, including non-members and available for consultation at least three days in the week and some evenings and some Sundays, as soon as the Institute is in permanent quarters.

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FIFTH.—Rare books, that is, books which it is practically impossible to replace, to be exhibited under glass with suitable explanatory cards and to be subject to closer examination only at the library and upon suitable introduction of the visitor to the Library Committee or their representative, the Librarian, and under such other precautions as will positively assure the preservation and safety of the books.

And further, it is my earnest desire that the INSTITUTE shall within five years, raise a sufficient fund by subscription, and provide itself with a permanent home for its meetings and library, and that this home shall be centrally located, reasonably safe from fire and not heavily mortgaged.

In case of the failure of the INSTITUTE to comply with the substance or spirit of these conditions, or with the desire expressed above for a permanent home, the library shall revert to me or my heirs or assigns.

Having in view the sole purpose of encouraging the INSTITUTE to attain the position which I feel sure all of its members desire, I have sought to name conditions easily within its reach.

SCHUYLER SKAATS WHEELER.

AMPERE, N. J., May 17th, 1901.

THE PRESIDENT:—The library has already been described, and you are therefore probably familiar with the fact that it is the finest library of its kind in the world. Not only is this a very valuable gift from Dr. Wheeler, which is in itself very valuable, but more than that it is the beginning of an effort to get for us a permanent home, a building where we can not only have our library, but our meeting room, a building which we can call our own. One of the purposes of Dr. Wheeler, as you have seen from his letter, is to lead to the accomplishment of that very desirable object. With such a start as he has given us, we hope, in the course of a few years, to accomplish this much desired result. The gift of Dr. Wheeler has already borne fruit in this way, that your officers and committees have recently visited Mr. Carnegie and have secured from him a very generous offer to give us for the maintenance of our library a sum of money equivalent to its cost. This has not been announced before, because we could not accept the generous offer of Mr. Carnegie until we had received the gift of Dr. Wheeler. Dr. Wheeler's gift having been presented to-day, Mr. Carnegie's gift can also be considered as having been presented to us to-day. [Applause.]

MR. C. O. MAILLOUX:—Although it is likely that the Council and the Library Committee will, at some future time, give fitting expression to the gratitude of the INSTITUTE in a proper manner, yet I think that the members present ought to put on record their own appreciation of these generous gifts by a vote of thanks. Dr. Wheeler is entitled to our gratitude, not only for the intrinsic value of the unique collection of books which he has just donated to the INSTITUTE, some of them of priceless worth, but also because he has set a beautiful example of gener-

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osity, which it is hoped may act as a precedent and incentive for others who like him are so fortunately situated as to be able to spare some of this world's goods to help a worthy cause.

I wish to commend particularly the altruistic tone of Dr. Wheeler's letter to the admiration, and for the emulation of the members. He has, on many occasions in the past, shown proof of his public spirit and zeal in studying and fostering the welfare of the electrical engineering profession, and of this INSTITUTE. In this gift he again illustrates and fortifies precept by example, and lives up to his convictions in a manner most acceptable, and, at the same time, highly impressive and edifying to this INSTITUTE.

I do wish therefore to move, and I ask the members to join me in a vote of thanks to Dr. Wheeler for his generous gift of the Latimer Clark library to this INSTITUTE.

[The motion was seconded and unanimously carried.]

MR. CHARLES P. STEINMETZ:—I also move a vote of thanks to Mr. Andrew Carnegie for his generous gift, which enables us to properly establish and maintain this library which we have received as a present from Dr. Wheeler. [Adopted.]

The Secretary then read the following telegram:

"International Hotel, Niagara Falls, N. Y.,
"May 21, 1901.

"Carl Hering:

"President AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, 12 West 31st Street, New York.

"Members of the INSTITUTE OF ELECTRICAL ENGINEERS attending the Convention of the National Electric Light Association send greetings and congratulations upon the gift of the Latimer Clark library by Dr. Wheeler. (Signed): T. C. Martin, Calvin W. Rice, Chas. F. Scott, W. E. Goldsborough, H. H. Humphrey, A. J. Wurts, D. R. Lovejoy, E. H. Mullin, Joseph Sachs, E. F. Peck, J. I. Ayer, Wm. Brophy, W. B. Jackson, H. A. Lardner, Paul M. Lincoln, J. B Cahoon, and many others."

The Secretary read the following reports of the Council, and of the Treasurer, which were accepted and ordered filed.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF COUNCIL FOR THE FISCAL YEAR ENDING APRIL 30, 1901.

The Council submits herewith, for the information of the membership at large, a report of its work during the past year, as well as the financial standing of the INSTITUTE.

Two meetings of Council and nine meetings of the Executive Committee have been held during the year.

The Committee on a National Standardizing Bureau continued its work during the year and up to the date when the bill for the establishment of this bureau passed in Congress. Not only was a large amount of correspondence carried on by this committee in furtherance of the bill, but members of it visited Washington and appeared in its behalf before the Congressional Committee.

The binding of the periodicals which have accumulated during the past thirteen years and the shelving of the same has been finished as far as possible during the year. Some of the files are incomplete, but are being filled up through the liberality of various members, and the collection is already of considerable value. To this will soon be added the magnificent Latimer Clark Library purchased for the INSTITUTE and presented by Dr. Schuyler Skaats Wheeler; also complete sets of "Comptes Rendus de L'Academie des Sciences," presented by C. O. Mailloux, and of the "Proceedings of the Royal Society of London," by Edward Caldwell. Mr. Andrew Carnegie has very generously offered to duplicate the amount paid by Dr. Wheeler for the Latimer Clark Library, which sum will be available for completing and cataloguing the collection. F. P. Fish, Esq., has also kindly donated $100 toward a Library of Patents. The INSTITUTE will therefore soon possess the most complete electrical library in the world. It has been necessary to rent another room in the Havemeyer Building for the present accommodation of about 10,000 volumes.

The work of the Committee on Revision of the Constitution has been continued, resulting in a practically new instrument, which was approved by Council April 26, 1901, and notice given at the INSTITUTE meeting on that date that it would be brought up for consideration at the annual meeting May 21, 1901. In accordance with a vote of the INSTITUTE the proposed Constitution was printed and appeared in the April issue of the TRANSACTIONS.

For the convenience of members residing at a distance from New York City, the date of meetings was changed from the fourth Wednesday to the fourth Friday of each month. Several members, especially those connected with colleges, have expressed their appreciation of that change.

Pursuant to the action of Council last year, arrangements were entered into for a joint meeting with the Institution of Electrical Engineers of Great Britain, which was held at Paris, August 16, 1900, in the National Pavilion of the United States on the Exposition grounds. The discussion at this meeting and also a report of the delegation to the International Electrical Congress which followed have been printed in the TRANSACTIONS. Resolutions of acknowledgment and thanks to the Institution of Electrical Engineers of Great Britain for the many courtesies extended to our members were adopted by Council, and under direction of a special committee an

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engrossed copy of the same has been executed and forwarded to that society.

It was decided to hold the next general meeting of the INSTITUTE at Buffalo, and a special committee was appointed to prepare a programme. A preliminary schedule has been printed and 4,250 copies sent to European electrical engineers, together with a circular letter inviting them to attend this meeting. The Institution of Electrical Engineers, being practically committed to a trip into Germany this season, could not officially accept our invitation to visit America this year, but as the Buffalo meeting occurs two months later it is hoped that many members may find it convenient to attend.

Continuing the practice begun last year, the Executive Committee, on February 28, 1901, authorized the purchase of $2,000 in Government bonds, out of which a sufficient amount has been placed to the credit of the Compounded Membership Fund to cover all payments made for life membership up to the date of this meeting. This purchase makes a total of $7,000 in Government bonds now owned by the INSTITUTE

The 149th Meeting of the INSTITUTE was organized as a dinner on January 9, 1901, and was held at "The Arena," on 31st Street. About 100 members and guests were present and there was a topical discussion on "Electricity in the Last Century and in This." The event was considered a success and greatly enjoyed by all

On February 8 the Committee on Papers and Meetings outlined a programme for the first Conversazione held by the INSTITUTE. Eleven regular and special meetings of the committee were devoted to this work between February 8 and April 10. The suggestions offered were approved by the Executive Committee. The interest aroused by this Conversazione and the attendance (about 1,000) surpassed all expectations of the committee. It resulted in the acquisition of many new candidates for membership and renewed enthusiasm on the part of officers and members. The thanks of the INSTITUTE are due to Columbia University and the exhibitors for their hearty co-operation with the Committee on Papers and Meetings; also to the members of this committee for their faithful and arduous labors.

There have been held during the year one general meeting at Philadelphia and Paris, the annual business meeting and eight monthly meetings at New York City.

The Board of Examiners has held ten meetings during the year, at which fifty-five applications for transfer have been considered. Of this number thirty-four were recommended to Council for transfer, seventeen held over for additional information and four disapproved.

The total membership at the close of last year's report was 1,183, classified as follows:

Honorary Members	2
Members	374
Associate Members	807
Total	1,183
Associate Members elected May 1, 1900, to April 30, 1901	151
Associate Members elected the previous year and since qualified	20
Total	1,354

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Resignations have been received and accepted during the year from the following members and associates who were in good standing:

Members—J. W. Lattig, A. Floyd Delafield, Victor M. Berthold, Thomas R. Taltavall.

Associate Members—Cleveland Abbe, George H. Blaxter, Walter A. Childs, R. K. Dana, James W. Gladstone, T. T. P. Luquer, Charles K. Munns, Henry A. Rowland, A. A. Serva, Alex. Vosmaer, E. R. Keller, J. P. Labouisse, W. E. Lindsay, A. J. Wood, H. E. Dey, J. P. Hall.

Total Resignations	20

There have been the following deaths during the year:

MEMBERS:

GEORGE W. GARDANIER, GILBERT WILKES,
ISAIAH H. FARNHAM, ELISHA GRAY.

ASSOCIATE MEMBERS:

JOHN E. HUDSON. JOSEPH CLEMENT,
W. M. T. WEISE.

Total Deaths	7
Dropped as delinquent	46
Elected, but not yet qualified	21
Total	94

Leaving a total membership of 1,260 on May 1, 1901 (a net gain of 77, the net gain for the previous year being 45), classified as follows:

Honorary Members	2
Members	387
Associate Members	871
Total	1,260

A list of associate members elected during the year accompanies this report, and the names appear in the printed TRANSACTIONS.

The reports of the Secretary and of the Treasurer show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of receipts and disbursements during the entire year:

SECRETARY'S BALANCE SHEET.

FOR THE FISCAL YEAR ENDING APRIL 30, 1901.

Dr.		*Cr.*	
Balance from previous year	$256 48	By Cash to Treasurer	$13,622 36
Receipts for the year	13,617 39	Balance to next year	251 51
	$13,873 87		$13,873 87

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ITEMIZED STATEMENT OF RECEIPTS AND DISBURSEMENTS OF THE INSTITUTE.

For Fiscal Year Ending April 30, 1901.

General Account.

Receipts.		*Disbursements:*	
Treasurer's Balance from previous year	$2,205 08	Revenue Tax	$12 35
Secretary's Balance from previous year	256 48	Bank Exchange	8 99
Entrance Fees	745 00	Chicago Meetings	30 06
Life Membership Fees (F. A. Saylor, J. D. E. Duncan, W. E. Chappell, Samuel Sheldon, W. J. Hammer)	500 00	Library	697 55
Past Dues	615 88	Ice	26 09
Current Dues	9,623 62	Laundry	8 25
Advance Dues	114 38	Office Expenses	37 33
Electrotypes Sold	60 79	" Fixtures	3 70
Transactions Sold	790 61	Express	196 79
" Subscriptions	351 90	Telegrams	11 89
Advertising	55 00	Stenography and Typewriting	978 90
Received for Special Binding	38 06	Stationery and Miscellaneous Printing	561 91
" " Congress Books	4 20	Postage	589 20
" " Inter't on U.S. Bonds	150 00	Messenger Service	20 74
" from F. P. Fish, Library Donation	100 00	Salary Account	2,541 64
Received for Badges	232 00	Meeting Expenses	192 19
" " Certificates	30 75	Rent—Offices and Hall	1,191 68
" " Conversazione Tickets	205 20	Engraving	596 83
		Binding	199 32
		Publishing Transactions	2,757 75
		Badges	200 90
		Certificates	15 25
		Copyright (2 Years)	10 00
		Engrossing Resolutions, etc	163 65
		Legal Expenses	30 00
		Typewriter Exchanged	77 50
		Catalogue Type	3 75
		U. S. Bond *a/c.* Life Membership	1,000 00
		U. S. Bond *a/c.* Reserve Fund	1,000 00
		Premium on Bonds	235 00
		Conversazione	1,036 75
		Secretary's Balance to next year	251 51
		Treasurer's Balance to next year	1,451 48
	$16,078 95		$16,078 95

Outstanding bills excepting $264.53 were paid in full April 27, 1901.

There is due the Institute $2,608.05, of which about one-half is probably collectible. The amount reported last year as overdue and probably collectible was $1,422.41. The actual collections have been $615.88.

The total receipts for the past year exceeded the previous year by $68.48, while the disbursements were $827.05 in excess of last year, showing an excess in growth of disbursements over the gain in receipts of $758.57. The net financial gain during the year was $1,476.43, as shown by the following summary:

Net Cash Receipts		$13,617 39
Disbursements, Excluding Bonds Purchased		12,140 96
		$1,476 43

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Property on hand according to inventory May 1, 1901:

Office Furniture and Fittings	$247 95
Badges	106 00
Catalogue Type and Cases	186 82
Library	1,615 00
Transactions on Hand	3,419 50
Congress Books	532 50
	$6,107 77

TOTAL NET ASSETS.

Treasurer's Cash Balance	$1,451 48
Secretary's Cash Balance	251 51
U. S. Registered Bonds	7,000 00
Property as Inventoried	6,107 77
	$14,810 76
Total Assets last year	12,199 08
Increase	$2,611 68

Respectfully submitted for the Council,

RALPH W. POPE,

Secretary.

TREASURER'S REPORT.

FROM APRIL 30, 1900, TO MAY 1 1901.

GEORGE A. HAMILTON, TREASURER, in Account with
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from April 30, 1900	$2,205 08
Received from Secretary, April 30, 1900, to May 1, 1901	13,622 36
	$15,827 44

Cr.

Disbursements from May 1, 1900, to May 1, 1901, on Warrants from Secretary, as approved by Council or Executive Committee, Nos. 1230 to 1357 inclusive	14,375 96
Balance to New Account	1,451 48
	$15,827 44

By direction of the Executive Committee the Secretary and Treasurer have purchased during the year $2000 in 5% Government Bonds, for which a premium of $235 was paid. These have been added to the funds existing last year, which now stand as follows:

	FACE VALUE.	MARKET VALUE.
Building Fund	$1,000 00	$1,095 00
Compounded Membership Fund	3,000 00	3,285 00
Reserve Fund	3,000 00	3,285 00
	$7,000 00	$7,665 00
Treasurer's Cash Balance in Bank, Carried Forward to next year	1,451 48	
	$8,451 48	

Respectfully submitted,

GEO. A. HAMILTON,

Treasurer.

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It was voted that the reports as printed be accepted and filed.

REPORT OF PROXY COMMITTEE.

Mr. Maver read the report of the Committee on Proxies as follows:

R. A. Byrnes	1	Cary T. Hutchinson	1
George F. Sever	1	Samuel Sheldon	2
William J. Hammer	1	A. E. Kennelly	1
Charles F. Scott	1	Cecil P. Poole	1
Edwin W. Hammer	2	Calvin W. Rice	1
Carl Hering	8	John J. Carty	1
W. A. Anthony	1	F. A. Pickernell	1
E. P. Thompson	1	George A. Hamilton	2
F. A. C. Perrine	1	Blank	14
Fitzhugh Townsend	1	Gano S. Dunn	2
William D. Weaver	4	L. B. Stillwell	2
Ralph W. Pope	143		
Francis B. Crocker	2		198
Charles P. Steinmetz	8		

WM. MAVER, JR.,
G. A. HAMILTON,
Proxy Committee.

The amended Constitution as reported by Council and printed in the April, 1901 issue of the TRANSACTIONS, was then taken up by the meeting for final consideration, and after considerable discussion was adopted by a vote of 56 affirmative and 3 negative, the proxies not being called for.

Dr. Arthur E. Kennelly then presented the following paper on "The New Edison Storage Battery."

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A paper presented at the 18th Annual Meeting of the American Institute of Electrical Engineers, New York, May 21st, 1901, President Hering in the Chair.

THE NEW EDISON STORAGE BATTERY.

BY ARTHUR E. KENNELLY.

I take pleasure in bringing to the notice of the INSTITUTE, this evening, a novel type of storage battery, recently invented by Mr. Edison.

It is well known that the history of the storage cell is essentially that of the lead cell discovered by Planté in 1860, in which lead peroxide is the depolarizing substance. An enormous amount of labor has, in the aggregate, been expended upon the improvement of this cell in the hands of experimentalists. As a result of that labor, the storage battery has at last become a recognized adjunct to direct-current central stations, but it has limitations that seem to withstand further attempts toward improvement. Of recent years, hardly any success has been met with in the direction of reducing its weight for a given energy-storage capacity, without detriment to endurance, and this weight is the great drawback of the storage battery in electric storage traction, and has been the principal obstacle to its advance in this direction for the past twenty years.

In practice, the storage energy per unit mass of the modern lead battery, is from four to six watt-hours per pound of battery (8.8 to 13.23 watt-hours per kilogramme). Expressed in another way, a battery weighs from 124.5 to 186.5 pounds per horse-power-hour at its terminals (75.5 to 113.4 kilos per kilowatt-hour); or, if its stored energy available at terminals were all expended in gravitational work, a battery could raise its own weight through a vertical distance of from two to three miles (3.2 to 4.8 kilometres).

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While it is possible to increase the energy per unit mass by making the electrodes very light, yet this is always found to be followed by a very heavy deterioration.

Many attempts have also been made to perfect storage cells of the alkaline-zincate type, but the great difficulty of depositing zinc in coherent form from the solution, as well as the lack of a depolarizer that shall be insoluble in the electrolyte, has stood in the way of this cell's success.

Mr. Edison set himself the task of finding a cell which should possess the following advantages:

1. Absence of deterioration by work.
2. Large storage capacity per unit of mass.
3. Capability of being rapidly charged and discharged.
4. Capability of withstanding careless treatment.
5. Inexpensiveness.

He believes that the cell here shown may claim these advantages in a very satisfactory degree.

The negative pole, or positive element, corresponding to the zinc of a primary cell, or the spongy lead of a secondary cell, is iron. The positive pole or negative element, corresponding to the carbon of a primary cell, or lead peroxide of a secondary cell, is a superoxide of nickel believed to have the formula NiO_2. The cell is therefore a nickel-iron cell, a name which suggests the structural material—nickel-steel. The electrolyte is potash; viz., an aqueous solution containing from 10 to 40% by weight, but preferably 20%, of potassium hydroxide, the freezing temperature of which is 20° below zero F. or −30° C.

The initial voltage of discharge after recent charge is.... 1.5 volts
The mean voltage of full discharge is approximately.... 1.1 volts
The normal discharging current rate per unit area of active element (positive or negative) is..... 60 $\frac{\text{milliamperes}}{\text{sq. inch.}}$
or..... 8.64 $\frac{\text{amperes}}{\text{sq. foot}}$
or..... 0.93 $\frac{\text{amperes}}{\text{sq. decimetre.}}$
The storage capacity of the cell per unit of total mass of the cell is..... 14 watt-hours per pound
or..... 30.85 watt-hours per kilo
Expressing the same statement in another way, the weight of battery per unit of electric energy at terminals is
53.3 lbs. per E. H. P. hour
or..... 32.4 kilos per kilowatt-hour

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Or the battery gives energy at its terminals sufficient to lift its own weight through a vertical distance of approximately ....7 miles or 11.26 kilometres.
The mean normal discharging power-rate per unit mass of total cell is .....4 watts per lb. or 8.82 watts per kilo:
Corresponding to a normal discharge period of.....3½ hours
The cell may, however, be discharged at a relatively high rate, in approximately.....1 hour:
Corresponding to a discharging power rate per unit of total cell mass of.....12 watts per lb. or 26.46 watts per kilo.
Charging and discharging rates are alike. That is to say, the cell

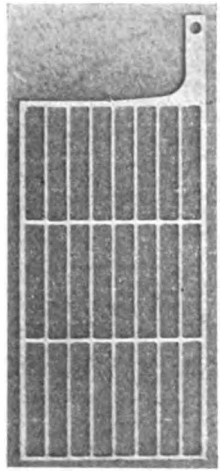

FIG. 1.—Nickel-plated steel grid for either positive or negative plate.

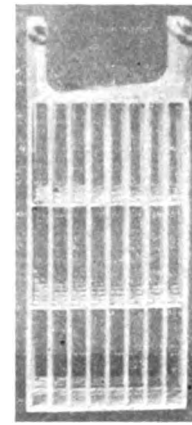

FIG. 2.—Assemblage of grids in the grouping corresponding to that of a completed cell.

may be charged at the normal rate in 3½ hours; or, it may be charged at a relatively high rate in one hour, with no apparent detriment beyond a somewhat lowered electrical charge efficiency. In other words, the cell does not appear to be injured by over-charging or discharging, and only suffers in electrical efficiency under such treatment.

The positive and negative plates are mechanically alike, and can scarcely be distinguished by the eye. They differ only in the chemical contents of their pockets. The samples here exhibited, which are intended for automobile batteries, illustrate the

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construction. Each plate is formed of a comparatively thin sheet of steel, 0.024″ (0.61 mm) in thickness, in which rectangular holes are stamped, so as to leave a grid or frame somewhat resembling a window-frame. In the plate here shown, there are three rows of eight such rectangular holes or recesses, or 24 recesses in all.

Each opening or recess is filled with a pocket or shallow box containing the active material. These boxes correspond to the panes of glass in the window-frame analogy. The panes instead of being thinner than the frame, as in an actual window, are thicker than the frame, or project slightly beyond the surface of

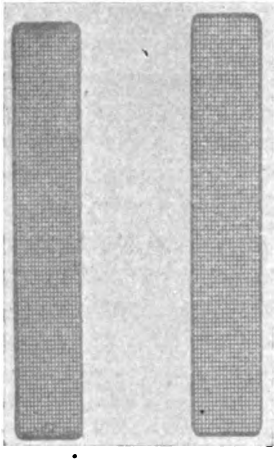

FIG. 3.—Perforated nickel-plated steel box and lid for containing the active material.

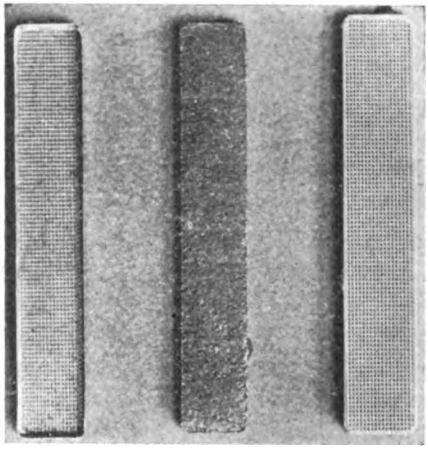

FIG. 4.—Steel box, lid and briquette of active material, ready for insertion.

the steel grid. They are perforated with numerous small holes to admit the electrolyte, but entirely conceal the contained active material from view. All that meets the eye, therefore, in any of the plates, is the steel frame, and its embedded "windows" of perforated steel.

The active material is made in the form of rectangular cakes or briquettes, and one such briquette is lodged in each pocket or "window pane" of the plate. Each of the plates shown, therefore, supports, or contains, 24 briquettes of active material, all in rigid contact with its own substance.

Each briquette is placed in a shallow, closely fitting nickel-plated box of thin perforated crucible steel, cut from a long strip

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of that material 0.003″ (0.075 mm.) thick. A cover or lid of the same material is then laid over it, so that the briquette is closely enveloped by the sides and walls of its perforated steel box. The boxes are then placed in the openings or holes in the nickel-plated steel grid, and closely fit the same. The assembled plate is then placed in a hydraulic press, and subjected to a total pressure of about 100 tons. This pressure not only tightly closes the boxes, but it also forces their metal sides over the adjacent sides of the recesses in the steel grid, thus clamping the whole mass into a single solid and rigid steel plate with the hollow "window panes" full of active material. The nickel-plating of both grids and boxes aids in securing good permanent electric connections between them. The finished plate has a grid thickness of 0.024″ (0.61 mm.), and a "window" or pocket thickness of 0.1″ (2.5 mm.). This is the maximum thickness of the plate at any point, but being of steel, the plate has ample rigidity.

The positive briquettes (zincs of a primary cell) are made by mixing a finely divided compound of iron, obtained by a special chemical process, with a nearly equal volume of thin flakes of graphite. The graphite does not enter into any of the chemical actions, but increases the conductivity of the briquettes. The graphite is divided into very thin laminæ by a chemical process, and these are passed through sieves or screens so as to leave a size or area of flake that is much larger than the area of the perforation in the steel windows. The mixture is then pressed into briquettes in a mould, under a hydraulic pressure of about two tons per square inch. The briquettes have a surface area of nearly 3″ x ½″ on each face.

The negative briquettes (carbons of a primary cell) are made by similarly mixing a finely divided compound of nickel, obtained by special chemical means, with a nearly equal bulk of fine flakes of graphite, and solidifying the mixture in a mould into briquettes of the same size as above.

A suitable number of positive and negative plates are assembled together, being separated from one another only by a thin sheet of perforated hard rubber.

The assembled plates are placed in a vessel or external containing cell of sheet steel containing the potash solution, which, of course, does not attack steel. There was, however, much difficulty from the action of the potash on the soldered seams of the steel containing vessel. After many trials, how-

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ever, Mr. Edison found a solder which seems to be entirely unaffected by the alkali.

In charging, the current is, of course, sent into the positive pole and its attached negative nickel-plate, through the electrolyte, and into the positive plate of the iron compound which carries the negative pole. This current deoxidizes or reduces the compound to spongy metallic iron and carries the oxygen through the film of electrolyte to the nickel compound, oxidizing it to the superoxide of nickel $Ni\ O_2$, a higher oxide than the peroxide. In other words, the charging current simply carries oxygen in

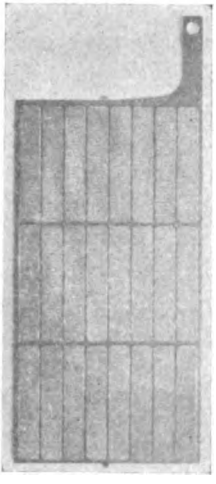

FIG. 5.—Assembled and completed single plate containing 24 briquettes of active material.

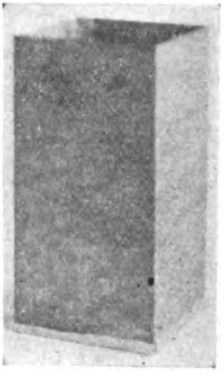

FIG. 6.—Sheet steel containing-cell.

the opposite direction against the forces of chemical affinity, from the iron to the nickel, and stores the energy in the reduced iron, which is, of course, unaffected and passive in the presence of the potash solution. On discharge, the current passes from the positive pole through the external circuit to the negative pole, and its attached iron or positive plate, and then through the solution to the negative or superoxide plate. In so doing the oxygen moves back against the current and partially reduces the nickel superoxide $Ni\ O_2$, while oxidizing the spongy iron. The energy of combination of the iron and oxygen which would be developed as heat in the ordinary chemical process, is now liberated in the circuit as electrical energy.

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The cell is an oxygen-lift. Charging pulls the oxygen away from the iron and delivers it temporarily to the nickel. The condition is then stable, until the circuit of the cell is completed. Discharge then allows the oxygen to fall back from the nickel to the iron by virtue of the natural affinity of iron and oxygen.

This action is very different from that which takes place in the lead storage cell. Here, neglecting complications, the action is usually regarded for practical purposes as being represented by the equation

$$PbO_2+2H_2SO_4+Pb=PbSO_4+2H_2O+PbSO_4+100 \text{ watt-hours},$$

where the left-hand side represents the condition of charge and the right-hand side the condition of discharge. Here oxygen is not simply transferred in discharge from the peroxide to the spongy lead, but the solution is changed (theoretically) from an aqueous solution of sulphuric acid to plain water. Of course the discharge could not practically be carried to the point of denuding the solution of all sulphuric acid, and a surplusage of acid must be used. The equation gives a mere theoretical outline of admittedly very complex reactions. In other words, the specific gravity of the sulphuric acid solution falls during the discharge, and the solution enters into the chemical combination. Theoretically, for every 445 grammes of active material on both plates, 196 grammes of sulphuric acid are required to effect the combination, or 44% by weight of the active elements, and in practice it is usual to allow a weight of sulphuric acid nearly equal to half the weight of the elements, or about one-quarter of the total weight of the cell.

In the new Edison cell, on the other hand, the theoretical action of the potash solution is merely to provide the proper channel through which the oxygen ions may travel in one direction or the other—positive plate to negative plate in charge, and negative plate to positive plate in discharge. Consequently, the amount of solution needs only to be sufficient to fulfill mechanical requirements. It is believed that the weight of solution will in practice be only about 20% of the plate weight or about 14% of the cell weight. In fact the cell may be worked in the same manner as the so-called primary "dry-cells." Moreover, if the solution should escape, or be carried away, by gasing in charging, the only detriment seems to be the loss of active surface thereby occasioned, and it will only be necessary to fill up

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the cells to the proper level with water from time to time, as evaporation or gasing may lower the level. For the same reasons the specific gravity of the electrolyte does not appreciably vary during charge and discharge.

The briquettes of active material slightly expand on receiving oxygen, and slightly contract on delivering it, that is to say, the iron briquettes contract and the nickel briquettes expand during charge, while on discharge the iron briquettes expand and the nickel briquettes contract. The level of the solution is in this way scarcely affected. The expansions and contractions of the briquettes appear to be well within the elastic limits of the spring-steel containing boxes, and consequently the electric contact is always secure. The covers or sides of the window pockets merely approach to or recede from each other slightly during charge and discharge. Fortunately, steel is the metal which possesses this mechanical elasticity in a marked degree.

The action of the charging and discharging current upon the briquettes seems to be transferred from their external surfaces inwards in a manner similar to the transfer of carbon and oxygen in the process of making malleable cast-iron in the furnace on the principle of cementation. No active material has been found to be ejected from the briquettes through the window perforations, even under deliberate overcharging and discharging. Such gas as is thereby produced makes its appearance on the external surface of the windows.

If the nickel compound had no affinity for oxygen, so that energy was neither developed nor absorbed in the deoxidation or further oxidation of that substance, then the energy would be entirely that due to the energy of combination of oxygen and iron, stated to be 79.7 watt-hours, and representing an E. M. F., theoretically obtainable, of 1.47 volts. If the combination of oxygen with the nickel compound be exothermic or energy-releasing, then the watt-hours delivered (and the E. M. F.,) will be lessened by the energy necessarily paid back to break up the combination.

If on the other hand the combination is endothermic or energy-absorbing, then the watt-hours delivered (and the E. M. F.) will be increased by the energy restored on breaking up the combination. Since the superoxide seems not to have been known hitherto, no information concerning its energy of combination is obtainable. The electromotive force of the cell seems to be so

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near to that of the union of iron and oxygen as to suggest that the nickel superoxide is not far from being neutral, or that the nickel compound has but little affinity for oxygen, although the superoxide appears to be quite stable in the cell.

The new cell does not seem to be appreciably influenced by changes of temperature, and should stand a very low temperature without detriment. The electrolyte—potash—does not attack any of the ingredients of the cell, nor are any of the ingredients soluble therein. No local action occurs in the cell so far as has yet been observed, since the E. M. F. is below that necessary to decompose water.

The cell may be fully discharged to the practical zero point of E. M. F. without detriment. In fact, a cell has not only been completely discharged, but recharged in the reverse or wrong direction, and after bringing it back to its originally charged state by proper restoration of the direction of charging current, the storage capacity remained unaffected. It would seem, therefore, that the cell should be capable of withstanding much abuse.

Diagrams are appended giving the curves of discharge of experimental cells.

Fig. 7 shows a six-hour discharge curve from observations upon a small experimental Edison cell, but with the current strength increased in such proportion as to represent the delivery of a cell weighing 21 lbs. Fig. 8 shows a $3\frac{3}{4}$-hour discharge of the same cell. The outfit is approximately the same in both cases. The comparatively sudden drop in pressure or bend in the curve indicates a change in the electro-chemical action of the cell at a certain point of exhaustion of the iron plate.

Mr. Edison states that "the negative plate (nickel) either charged or discharged, can be removed from a working cell, and dried in the air for a week, without appreciably injuring it, and when the plate is finally replaced in the cell its charge is practically undiminished."

The positive (iron) plate, if similarly removed from the cell will be likewise uninjured, but it soon loses its charge by the oxidation of the spongy iron with accompanying liberation of heat and appreciable rise of temperature extending over a period of several hours. On replacing the electrode, however, in the cell, the storage capacity is unaffected on recharge.

As regards cost, Mr. Edison believes that after factory facili-

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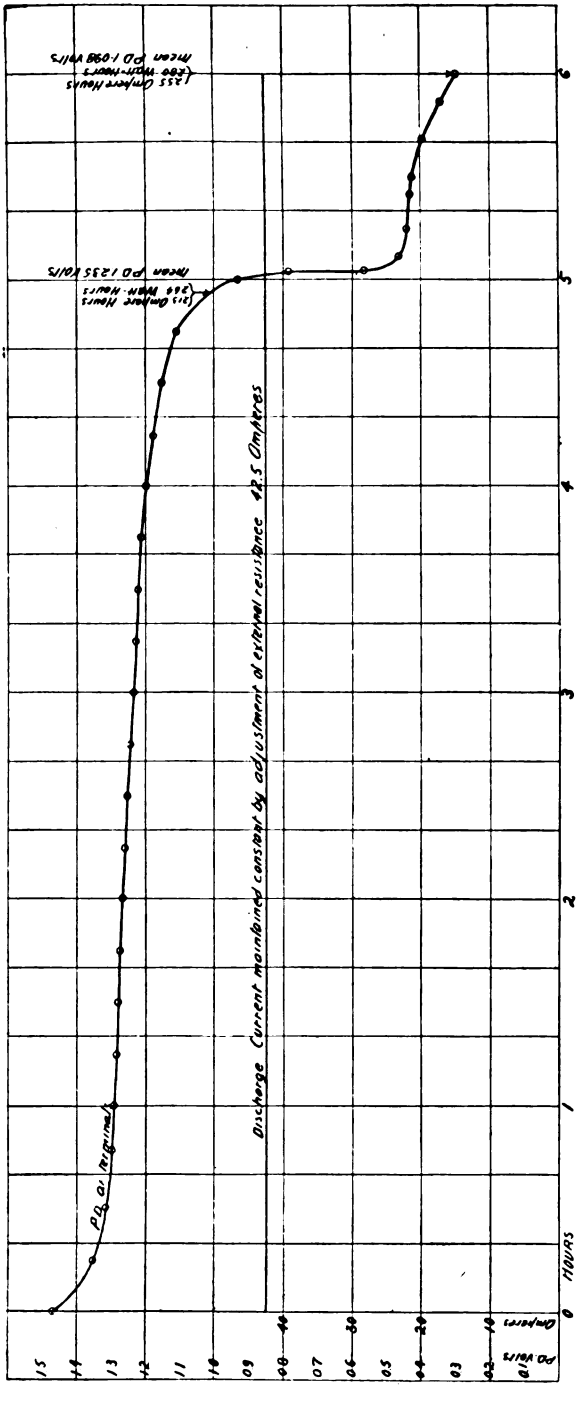
Discharge Current maintained constant by adjustment of external resistance 42.5 Ohmores
Mean PD 1.235 Volts
Mean PD 1.098 Volts
HOURS

Fig. 7.—Discharge Curve of Experimental Edison Cell, referred to a cell of 21 lbs. weight. Six-hour discharge at constant current.

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ties now in course of preparation have been completed, he will be able to furnish the cells at a price per kilowatt hour not greater than the prevailing price of lead cells.

Having now considered the action and properties of the cell,

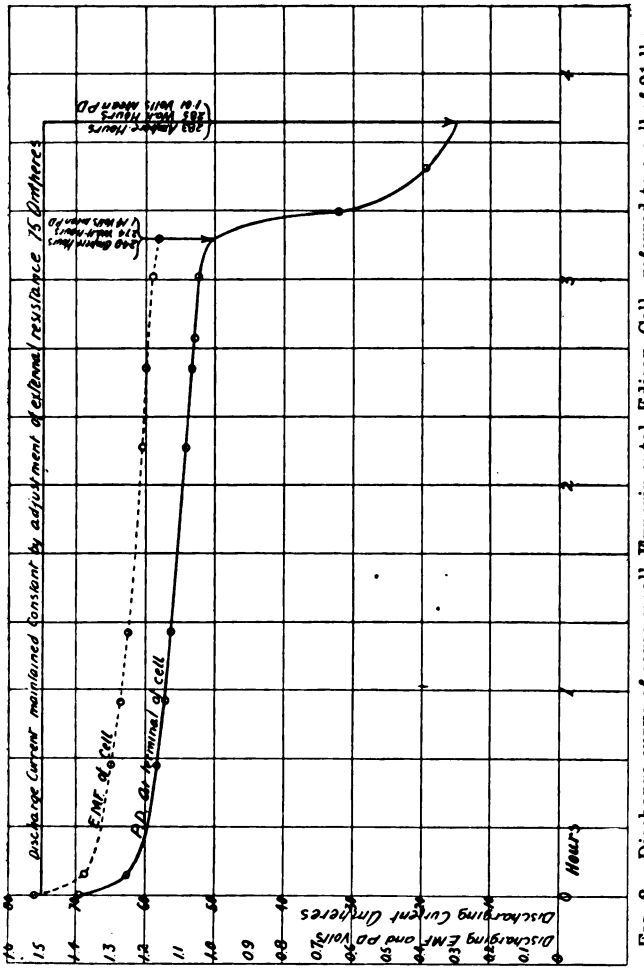
Discharging Current Ampères
Discharging EMF and PD Volts
Hours
Discharge Current maintained constant by adjustment of external resistance 15 Ampères
E.M.F. of Cell
P.D. at terminal of cell

FIG. 8.—Discharge curve of same small Experimental Edison Cell, referred to a cell of 21 lbs. weight. 3½-hour discharge at constant current.

a brief description may be given of the difficulties encountered in developing it.

The phenomenon of passivity has probably kept inventors from finding this cell in the past. Mr. Edison believes that of all the very numerous compounds of iron, and of which he has tried many hundreds, the particular compound which he prepares, is perhaps the only one capable of being used.

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If the dried hydrates, or oxides of iron, native or artificial, are subjected to electrolytic reducing action in any alkaline solution, they remain inert and unaffected.

On the other hand, if finely divided iron obtained by reducing a compound of iron under the action of a reducing agent, such as hydrogen, or carbonic monoxide is subjected to electrolytic oxidation in an alkaline solution it is inert and cannot be oxidized. It assumes the well known passive state.

The same difficulty of passivity affects the use of nickel or the negative element. Finely divided nickel, reduced from a nickel compound, remains inactive when subjected to electrolytic oxygen in an alkaline solution. The monoxide and the black-oxide or peroxide are also inert. No oxide of nickel is active or can be made active by electrolytic action, and the peroxide does not act as a depolarizer.

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Discussion.

Dr. Kennelly:—Summing up, then, you will observe that the substances of which the cell is composed are steel and iron, those substances which are so enormously important in engineering generally. It is from steel and iron that the structures of mechanical and civil engineering are produced. It is steel and iron that have given us dynamos and dynamo-electric machinery for the transmission of electric power. Without steel and iron we would not be able to employ electricity commercially in such applications. Let us hope that steel and iron may be similarly the foundation of a great improvement in the storage cell. By a curious coincidence, all the active substances in this cell are distinctively magnetic—iron, nickel and the working substance, oxygen. The real difficulty presented, as Mr. Edison states it, was in finding salts of iron and nickel which would work, which would not remain passive, and I understand him to say that he has practically had to find new substances, in the sense of substances under conditions not recognized or known—virtually new salts, which would be capable of activity, of charging and discharging in this way.

Dr. N. S. Keith:—Mr. President, calling to mind the old adage that the "proof of the pudding is in the eating," we can add that it rests also in inverse ratio to a man's digestive disturbance, for good pudding. I do not wish to criticise this cell, because I have not figures enough, and have not facts enough under which to criticise. I hope that it is going to be all that is said for it this evening. But I notice that there is an absence of curves of charge to compare with the curves of discharge. It is by comparing those, we determine the cost of storing and utilizing the electrical energy. We seem to have a new chemistry given to us, as well as a new electrolytic cell. We have here a mixture with graphite, a recognized strongly electro-negative material. I will grant you that graphite, iron and nickel have very little difference in their electro-motive forces when immersed in a solution of potassium hydroxide. But we have changes of those conditions. Under charge we get a so-called new oxide of nickel, something beyond a peroxide of nickel—a hitherto unknown thing, an exceedingly electro-negative material under the conditions, and it is associated with graphite, a less electro-negative. When told that there is no local action, to a chemist it seems there must be some mistake, or else there is a new chemistry. Then again, when we have oxide of iron we have a like condition of a highly electro-negative material, graphite, in combination, in close contact with a more highly electro-negative oxide of iron, and that there is no local action taking place seems to me at least astonishing. I will bow to results and say that he must be dealing out a little different chemistry from what we have been taught up to the present time. I think that we should not put out in a scientific paper read here, a statement like this—that "the cell is an

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oxygen lift;" that is, it is simply a transmitter of oxygen from one place to another, as though it was directly done—taken from one plate, carried over and put in the proper place on another. Electro-chemists know that no oxygen can be transferred from one place to another in an electrolyte without secondary actions and reactions taking place. I suggest that before this be put out to the world, it be modified on that point, so that we will not, as a scientific body, issue an imperfect statement of that kind. In general, common, every-day language, in explaining things to a layman, we might say that oxygen was taken from one and put over to the other. Well, it is; but it is done in a more complicated way than it would seem to be by the statement.

Mr. Chas. P. Steinmetz:—The most striking feature of this new storage battery cell shown here, and especially striking to those who have anything to do with the lead accumulator, and especially those forms of lead accumulator in which an attempt is made to increase the output by reducing the weight—the most striking feature of this is the very solid and substantial mechanical construction. It is really a mechanical apparatus, apparently, and not a laboratory instrument, as the storage battery of the lead type actually is, or seems to be, and as experience seems to show it to be. I have no very extended experience; I have no very continued experience with lead storage batteries. I had an experience as far back as 1880, and I agree with Prof. Thomson when he told me once that he found a very satisfactory use for his lead storage battery—the best use he ever could put it to, and that was to melt it down and use it as a counter-weight in his telescope. There may undoubtedly be some very good use for the old material, and it has done some very good work, and is still doing work where weight is not essential, where you can have much weight and careful attendance. Still it is not a very mechanical structure, and this cell seems to offer certain advantages, and promises to be more mechanical and extremely neat, as we look at it here. As to the chemistry of this new cell, there seems to be something very mysterious—some peroxide which is very little known in chemistry. But we know that many of these metals, of the iron group especially, have iron oxides which are more or less stable, and at the same time I do not think we can make this an objection to the new accumulator, because no one has ever fathomed the chemistry of the lead accumulator, or come near to it. I stated that the most interesting and promising feature of the cell is the neat mechanical construction, which is very encouraging compared with other proposed and tried storage cells. Those people who know Mr. Edison's work will hardly find it astonishing, because we all probably agree that whenever Mr. Edison has brought out something, he has developed it mechanically so far that it is really a machine, a mechanical instrument, and not a laboratory toy.

Mr. Robt. McA. Lloyd:—I think we ought all to be grateful

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to Dr. Kennelly for his splendid presentation of this subject to-night. In the compass of a few pages he has laid before us a great deal of information for which we have been waiting.

I think we ought also to realize that this is the result of a long research by Mr. Edison, and that the INSTITUTE is fortunate in being the medium through which another great development in electrical science is made known to the world. While some of us have experimented with nickel and iron in storage batteries, I believe Mr. Edison has carried his investigations in this subject much further than anyone else, and the plates shown us to-night are worthy not only of our interest, but of our greatest admiration. On the other hand, I do not agree with Mr. Steinmetz in his statement that this is a mechanical success as compared with the old lead storage batteries. We have yet to find out the difficulties with this finely constructed iron instrument. It is hardly likely that it will last forever, and probably it will not be as ideal as we all hope it will be. These iron structures may possibly deteriorate in the presence of electrolysis, and the fact that has been suggested to us of the presence of graphite, points to other possible difficulties besides local action. There also seems to be a suggestion in Dr. Kennelly's paper that there is local action, inasmuch as he speaks of "initial voltage of discharge after receiving the charge." I would like to ask him whether any noticeable change had occurred in the voltage after standing on charge. The mean voltage is rather low compared with the initial voltage of the charge. Perhaps I did not understand his exposition of the curves, but from the mean voltage being 1.1 volts it looks as if the voltage must fall at times down to near half a volt. A large part of the capacity of the cell must therefore be delivered at a low voltage. The internal resistance is certainly high, quite as high as the internal resistance of the average storage battery in proportion to its watt capacity. The solution is also going to be troublesome if it is not chemically pure, because iron and other things are very likely to get into water, and of course are going to make trouble in that battery. Perhaps iron would not have any very serious effect, but there are many kinds of water which would very likely muddle up those briquettes of nickel in the course of two or three years. And looking at it broadly, it seems to me hardly likely that these fine plates and those briquettes are going to maintain their mechanical or chemical constituency for a very much longer period than the clumsy old lead laboratory instrument with which we are all familiar. The lead battery is clumsy, but after all it is just about as commercial, as far as we know, as this is likely to be. I do not feel that we have had enough experience with these cells to be able to predict anything about them. I only hope that they will be all that Mr. Edison believes them to be.

THE PRESIDENT:—If there is no further discussion, I would like to ask Dr. Kennelly whether the solution does not have to

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be protected from the air? I do not recall whether this is referred to in the paper.

DR. KENNELLY:—It is not mentioned in the paper.

THE PRESIDENT:—The trouble with the use of caustic potash in batteries of that kind is that it changes into the carbonate when in contact with the air, and it must therefore be protected with a layer of oil or something similar.

I would also like to ask whether there is not a strong corroding action on the lugs of the plates along the surface of the liquid, where both the air and the liquid are jointly or alternately in contact with the lugs of the plates.

MR. MAILLOUX:—I would like to ask Dr. Kennelly if he could give us some even approximate data in regard to the efficiency of the battery. He has given the mean voltage of discharge. Could he give us also the mean voltage of charge, so that we might obtain what Regnier has so aptly called the "coefficient of drop" or the ratio of the mean E. M. F. of discharge to that of charge? Could he also give us the mean ampere-hours of charge, so that we might obtain what Regnier also so aptly calls the "coefficient of restitution," or the ratio of the discharge ampere-hours to the charge ampere hours; that is, the relative yield in ampere-hours; the product of which two coefficients gives the absolute efficiency of a battery. In other words, could he give us either in watt-hours the amount of energy required to fully charge the cell to obtain a good normal discharge, or could he give us separately the two factors, voltage and amperes?

MR. H. G. STOTT:—There is one point I notice about this battery which in a practical way might be rather troublesome, and that is that the initial voltage of discharge is 1.5 volts. The mean point of discharge is stated as approximately 1.1 volts. There is a drop of about 26.6 per cent. Now, that change of voltage would have to be taken care of in practice by either a booster or end cells. I would like to ask how rapidly this fall of pressure takes place.

In the lead cell the voltage falls immediately from 2.5 to 2.2 as soon as the charge stops, and the practical discharging voltage is between the limits 2.1 and 1.8, or a variation of 14.3%, whereas with the Edison cell there is apparently a drop of 26.6%—calling for practically double the regulating apparatus necessary with the lead cell.

DR. KENNELLY:—I will do the best I can to answer the questions that have been put. In regard to the charging electromotive force, it commences at about 1.5 and ends about 1.6, and I suppose that 1.55 would be about the mean charging voltage. The discharging mean voltage of 1.1 includes a discharge carried down to as low as .3. As you saw on the last diagram (Fig. 8), if you carry the discharge only as low as one volt, the mean terminal potential difference of discharge would be more like 1.25 volts. Consequently, under those conditions, with a some-

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what reduced output, you would have a fall between 1.55 and 1.25.

As regards the graphite, I believe that that does not enter into any chemical action whatsoever. Whether it might ultimately do so on forcing the cell to extreme overcharge, I do not know; but it appears to be inert, according to the statements I have received. Its purpose is to improve the conductivity of the briquettes. I believe there is no sensible loss by local action. Mr. Edison states, in the passage I have quoted, that after a nickel plate was taken out and dried for a week, its ampere-hour capacity and, I suppose, also its watt-hour capacity, was not appreciably affected.

As regards the oxygen-lift question, I know that that is a rather popular way of expressing the matter, but I think it is justified in so far as we deal with the general resulting action. In the charged condition there is a relative superabundance of oxygen at the negative plate. In the discharged condition, there is a relative superabundance of oxygen at the positive plate. In charging, therefore, oxygen is transferred against the forces of chemical affinity from the positive to the negative plate. In discharging, the oxygen is transferred with the forces of chemical affinity. Now the action, of course, by which that transfer takes place is much more complicated, and I have not attempted to carry it out; in fact, I do not know it. Unless we all know accurately what the compound was and just exactly what that salt of nickel was—it is only assumed to be nickel peroxide—we could not attempt to map exactly the actions that occur. But whatever those actions may be, we know, broadly speaking, that after discharge there is more oxygen with the iron and less with the nickel, and on the contrary, the oxygen is transferred in charging; also that is the only ultimate change apparently taking place in the cell. It is fair to say, from a general, broad standpoint, that by charging you have lifted the oxygen away from chemical affinity and have pulled it out of its natural position, and when you let the cell discharge, you reverse that operation and allow the oxygen to return. Whether there are intermediate steps by which the ions go in different directions, etc., is a matter which we need not concern ourselves about and which it does not profit us at the first glance to enter into. When the chemistry of the subject is better understood, then these minute actions and the more correct phenomena will be understood.

I think I have answered Mr. Steinmetz's question. As regards NIO^2, the voltage fall is not, as I understand it, attributable to local action. The voltage fall is due, I presume, to a superficial exhaustion of the briquettes, and the consequent interposition of an obstacle to the action of the undischarged briquettes in their interior, and I suppose that fall of electro-motive force is due to the superficial layer of discharged substance. The drop in the cell is of course that permanent fall plus the IR drop. I do not think that I can answer accurately the questions concerning the

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precise amount of that current-resistance drop at different loads. I have not made any succession or series of observations upon the cells myself, and I only take the figures and results that have been given to me, and there is about 10% drop at a 3½ hour rate.

As regards the troubles from the solution, if not chemically pure, I suppose that may be safely admitted. If you do not have pure solutions you may have trouble, and it may be necessary perhaps to occlude the solution, as is done now with the Edison-Lalande cells, or in some other manner.

In regard to the volume comparison, I have not made any careful comparison. The cell is very compact, as you see, and it is essentially a steel cell as compared with a lead cell. It will be compact both by virtue of the thinness of the plates and by virtue of the small separation or clearance between the two. The coefficient of efficiency, so far as I know it, is simply represented by the comparison between the mean charging voltage of 1.55 approximately, and the discharging voltage of about 1.25, if you carry the discharge to the 1 volt point. As to the ampere-hour coefficient I do not know that.

I think that I have answered most of the questions which have been put to me.

Mr. Justus B. Entz:—I have experimented with both iron, steel and nickel plates, in alkaline solution, and, as Dr. Kennelly says, it is difficult to reduce the oxide or oxidize the pure metal. The higher oxide of iron that I have seen produced electrolytically under these conditions was soluble in the solution. There is apparently some intermediate oxide that is capable of being raised to a higher point and lowered again. I have never run across anything like it, and the composition of the cells was totally unexpected. The general difficulty which I have seen with the two metal cells as compared with the one metal cell like the lead battery, is local action; if in a lead battery any material from the positive plate should come off and get into the solution and attach itself to the negative, it will immediately be reduced to spongy lead and become part of the negative plate. There is no loss of energy except as represented by that amount of peroxide. But in any two-metal cell, as this; if nickel, for instance, which has a difference of potential from that of reduced iron, should get on the iron plate, local action would go on indefinitely. So that the presence of the slightest amount of material from the positive on the negative would create a local action which would go on indefinitely. That has been one of the greatest objections to a cell composed of different metals, and not simply oxides and reduced metal of the same metal, as in the lead cell; the alkaline solution itself, in my experience, has got to be covered with a layer of oil. I have also found it has quite a high internal resistance unless it is kept at a high temperature. With the copper-zinc cells it was necessary to keep the solution at a temperature of about 130° to enable it to do any commercial

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work. In regard to lead batteries such as are used to-day, a battery is being used very extensively which has a capacity of about 12 watt-hours per pound. Of course batteries can be constructed, and commercial batteries too, up to 15, 16, and more watt-hours per pound; but to-day a battery having a capacity of 12 watt-hours per pound and weighing from 30 to 35% of the weight of the vehicle will propel an automobile between 40 and 60 miles, according to the general size of the vehicle. That takes up quite a space in the vehicle. As this new battery has a less specific weight than the lead cell of the same capacity per pound, so, weight for weight, this style of cell would necessarily be more bulky.

DR. KENNELLY.—In giving these figures, you refer to the alkaline cell, not the lead cell.

MR. ENTZ:—Oh, yes, lead cells of a type such as have done about 100,000 miles last month in automobile service.[1]

MR. MAILLOUX:—There are several mysteries about this cell, more especially about the chemical structure and the reaction of the iron; but there is another thing which seems to me far more mysterious, if the explanation given be the whole explanation. We have heard of the transfer of oxygen and the reference to a means for "lifting the oxygen." Now, if the reaction involved be one which concerns oxygen only, then we have a mysterious case of selective electrolysis in which we have the evolution of ions only at one pole. Now, we know of no case in electrolysis where we have an anion without a cation. Certainly in this case, if the ordinary laws of electrolysis apply, every time that oxygen is transferred, a corresponding cation must also be transferred, not only during the charge, but during the discharge. I surmise that this must be the case in this particular instance, and that hydrogen must be the corresponding cation which is evolved. We know that iron can be reduced to its metallic state from its oxides by the action of hydrogen, and there are several forms of finely reduced iron, including the kind known as "iron by hydrogen" in pharmacy. Reduction of oxygen merely takes place by the operation of hydrogen in some form or other, in the nascent state, so-called, or in the peculiar condition evolved as an ion at the cathode. It would be interesting to have Dr. Kennelly state whether he has not heard from Mr. Edison that hydrogen performed its part in the mystery of the reactions of this battery. As for the O which he has used on the black board, to represent

1. The lead battery referred to is to-day largely employed by the New York Elec. Vehicle Transportation Co., 100 batteries are now in service and are doing an average mileage of 1,000 miles a month, while in some cases the average service is as high as 1,200 miles a month, and up to date 2,500 to 3,000 miles have been run with one set of batteries. The total mileage, on one charge, in the large electric broughams and hansoms, such as are commonly seen on the streets, is from 45 to 50 miles, in regular service.

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the mysterious undefined quantity of oxygen entering into the combination; I think it would be well to put a little sub "n" or a little sub "x" after the O.

Dr. Kennelly:—Of course it goes without saying that you cannot have an oxygen ion or a hydroxyl ion going one way without having a corresponding cation the other way. But all I maintain is that according to the results which have been stated to me, the solution is unaltered, and the salts which are formed in charge and discharge differ from each other essentially only in the oxygen or hydrated oxygen contents. The resultant change is essentially an oxygen change. The transfer of the cation may produce temporary chemical change, but no resultant change in the electrolyte.

Mr. Mailloux:—That is just exactly where I would differ from Dr. Kennelly. I would submit that unless gases be evolved there during the charge or discharge, then there must be a transportation of hydrogen ions to the cation side, and I would submit that those ions are quite as important in the reaction as the oxygen ions, and that no complete formula of the action which takes place can be made without taking into consideration the amount of energy necessary for that change of condition of the hydrogen or its transfer. There must necessarily be a transfer of hydrogen from the one plate to the other; when the oxygen goes to the positive plate, the hydrogen goes to the negative, and in the reverse action of the battery the reverse process must take place. It is equally certain that the complete reactions cannot be examined electrolytically or electrothermically without taking into consideration both of those constituents.

Mr. Edward P. Thompson:—Speaking about spongy iron—I understand that spongy iron was formed—of course that is iron with an absorbed gas, and that gas is probably hydrogen.

Dr. Williams:—I do not see any reason for bringing hydrogen into this at all. Potassium is what does migrate there. Potassium could be the reducing agent at the electrodes, it seems to me, unless hydrogen were found to be generated at the electrodes as gas.

Mr. Mailloux:—I accept the modification, because potassium might replace hydrogen, being also a strong electropositive substance. If, however, potassium is actually transferred, the solution density will not remain unchanged in charge and discharge.

Mr. Chas. J. Reed:—It seems to me that this battery is an exceedingly interesting one, and I for one feel like congratulating Mr. Edison on the results he has attained. The battery is interesting from a chemical standpoint, being of an entirely different type from any of the accumulators that have ever been put into practical use. There have been recently some others working in the same field, who have produced batteries of this particular type, but of other materials, not using iron or nickel. I had occasion recently to examine such a battery and was somewhat

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surprised at the results, some of which were exceedingly interesting. In the particular case that I refer to, a battery weighing about six pounds gave, in its best condition, a capacity of 80 ampere-hours with an average electromotive force of one volt, or something like 16 watt-hours per pound of complete cell. One

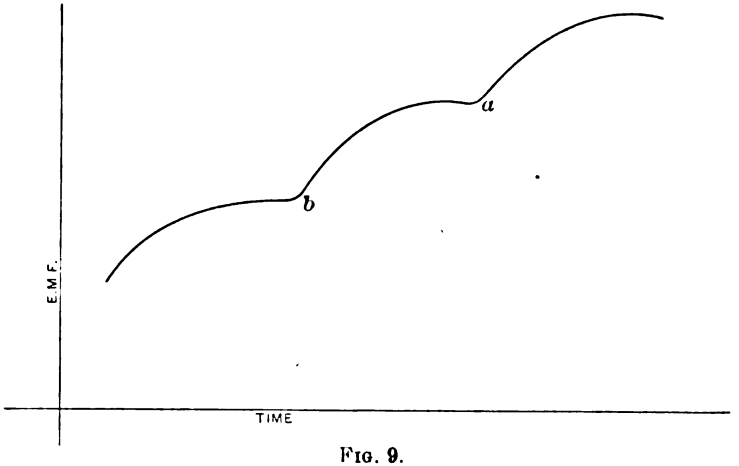

FIG. 9.

peculiarity in this particular cell was, that it showed in a much more marked degree than this battery of Mr. Edison the successive chemical changes which take place in the cell. The curves of charge and discharge, instead of being straight or being single

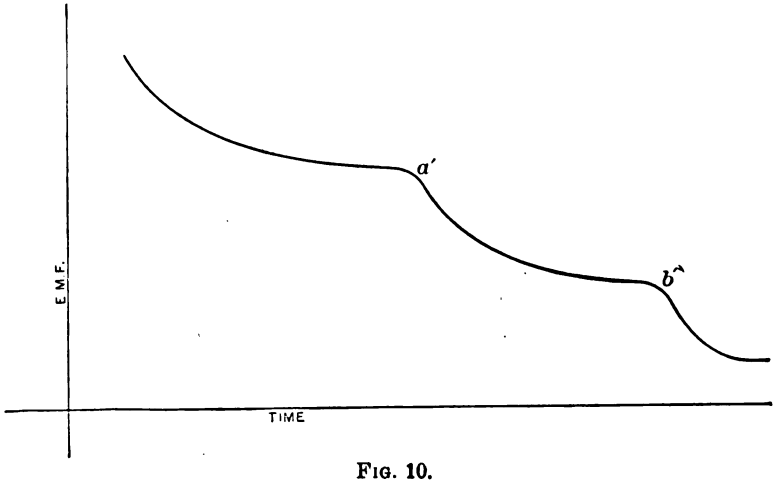

FIG. 10.

curves, were made up of several curves. The charge curve was of the form shown in Fig. 9. The electro-motive force at the beginning of the charge being about one volt, and at the end of the charge about two volts. The discharge curve was as shown in Fig. 10, the point *a* of the charging curve corresponding to the

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point a^1 in the discharge curve, and the point b corresponding to b^1, showing evidently that the electrical energy is not produced from a single chemical reaction, but that there are several chemical reactions taking place in succession. During the early part of the charge there is a chemical change which corresponds to one part of the curve. When in charging the battery, all the material has been converted into certain products, a second chemical reaction takes place which requires a higher electromotive force, and the absorption of more energy, then a third reaction. In the process of discharging, the chemical reaction, which required the absorption or the greatest energy, begins first to reverse and gives out the greatest energy. While this reaction is in progress the electromotive force drops down to the point a^1, and so on with the subsequent chemical reactions. One peculiarity of the cell examined by me was that at the points a and b the electromotive force actually fell below that which it had attained earlier and in discharging rose higher at a^1 and b^1 than at preceding points. In other words, in discharging with a uniform current the electromotive force dropped below the point a^1 and then rose again slightly to a^1, then dropped below b^1 and rose again to b^1.

It seems to me that a cell of this type is interesting particularly from three different standpoints. In the first place, an ideal battery is one in which the material will undergo as little motion as possible; the material which enters into the chemical reaction will remain in a certain fixed place. In any cell, in which the electrolyte takes part in the chemical action and combines with the substance of the electrode, that of course is impossible; the electrolyte must alternately go into and out of the electrode, causing not only mechanical disintegration but limiting the capacity of the cell by the quantity of the electrolyte. When the electrolyte of such a cell is exhausted to a certain extent, the capacity of the cell is ended, no matter how much solid active material you may have in the electrodes. Now, in the type of cell described here this evening that difficulty is eliminated. As Dr. Kennelly has stated, it is only necessary to have enough electrolyte to wet the plates, and the less you have and the closer your plates are together the better off you will be, because you have less resistance and less weight to carry. Another point which theoretically is of advantage in this type of cell is that the resistance tends to remain more constant. If we have at the start two electrodes, one of which is a metal and the other a metallic oxide, the metal is a good conductor, the metallic oxide is generally a good conductor, a much better conductor than metallic sulphates in the solid state. In the discharge of a cell of this type, the metal plate becomes an oxide, and the oxide plate becomes a metal. The change in resistance in general we should not expect to be so great as where a metal and a conducting oxide both became a non-conducting sulphate such as we have in the lead cell. Experience with the various types of alkaline zinc-copper batteries have shown that this is the case.

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There is one other chemical reason why this cell is exceedingly interesting. It may not be practical, but it points to a possibility which many of us have been looking for. If we suppose these plates to be made very thin, so that they could easily be washed; for example, if we imagine a battery to be constructed in such a way that we have a thin film of the metal on one plate and a thin film of oxide on the other, so that the alkaline solution could easily be washed out, it does not require a great stretch of imagination to step away from the dynamo altogether. In other words, when this battery is discharged, we can take the plates out of the solution, drain them off, wash out the alkali, and then we have simply got our oxygen transferred from one plate to the other as Dr. Kennelly has explained. What we want to do is to transfer the oxygen back again. Now, there are other ways besides electro-chemical action in which that can be done. For example, we have in this particular battery, assuming the formula given in the paper to represent the reaction, nickel hyper-oxide, as it is called in the paper, on one plate and metallic iron in a finely divided state on the other plate. The discharge of this battery would naturally result in the production of ferrous oxide and nickel monoxide. That would be the first step at least. Whether that would be final or not I would not want to say. But metallic iron would certainly not reduce the nickel to the metallic state unless the electro-motive force dropped to something like two-tenths of a volt, as the difference between the formation heats of nickel monoxide and ferrous oxide is very little. That of nickel monoxide is about sixty-one calories and that of ferrous oxide about sixty-nine. But suppose we have this battery in a discharged state. The nickel hyper-oxide is reduced to nickel monoxide; metallic iron is oxidized to ferrous oxide and we have the plates cleaned from impurities. It is a well-known fact that ferrous oxide can be converted back into metallic iron by simply heating it to about 300° C. in the presence of hydrogen, and it can also be done with carbon monoxide. It is possible also to find other ways by a dry or other thermo-chemical process of producing nickel peroxide or hyper-oxide, as it is called in the paper. I do not mean to say that we can charge this particular battery in this way, but I am speaking now in general of this type of battery. With iron I think it could very probably be accomplished. But if we should succeed in working out a thermo-chemical process for reducing the iron and re-oxidizing the nickel oxide, then we could charge this battery without the use of any dynamo or any electric current. In other words, the battery is not only a storage battery, but it is an instrument for transforming heat and chemical energy from other sources, such as carbon, carbon monoxide, or hydrogen into electrical energy. That would not, of course, be a direct process of getting electrical energy out of carbon; yet it might be an economical process. I think, therefore, that a cell of this type is interesting from these three reasons particularly.

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The theoretical capacity of such a cell would be about 160 ampere hours per pound of active material, while that of the lead cell is about 44 ampere-hours. I do not see any particular reason in the abstract why we should not be able to actually utilize as high a percentage of the total active material in this cell as in the lead cell. In fact, it seems to me that we might utilize a higher percentage from the very nature of this cell, because products formed by discharge are not non-conductors as in the case of the lead cell. One of the reasons why we can only utilize a small percentage of the material in the lead cell is that the product of discharge is a non-conducting substance which obstructs the current; whereas in this case the products on both electrodes remain conductors, the only difference being that the oxygen has changed from one plate to the other.

THE PRESIDENT:—What happens when a very strong charging current is sent through the cell; and what gases are developed then, if any? It would also be interesting to know something about the life of the cell; whether it has been charged or discharged frequently enough to show what the effect of repeated charges would be. I would also like to ask Dr. Kennelly whether that double knee in the discharge curve is due to a different chemical action than that in the main discharge, or perhaps to the fact that one of the plates was discharged, while the other was not; does he know whether both the plates had gone through tho first chemical reaction when the first knee was reached, and then went through a second to the second knee.?

DR. KENNELLY:—In regard to the first question, if the battery is heavily charged, gas is given off, certainly hydrogen is given off, and I have seen that effect taking place from the outside of the windows.

THE PRESIDENT:—Hydrogen on one and oxygen on the other, I suppose?

DR. KENNELLY:—I presume so. I am sure of the hydrogen; I am not sure about the oxygen. In regard to the durability of the battery, I am unable to make any personal statement. Mr. Edison has been working on the cell for a number of months, and he tells me he has had experimental cells charging and discharging repeatedly for some months without observing any depreciation in them. A cell of this kind requires special tools for its manufacture; a press, for example, which will bring 100 tons stress upon a plate, is a matter of some difficulty to obtain, and as a result it takes time to produce the first samples of a plate of the kind. The result of that has been that Mr. Edison has conducted his experiments entirely on some plates consisting of a small number of these pockets as distinguished from a completed plate of twenty-four. But of course the results obtained from the small number of pockets are capable of reduplication in the ordinary way, just as is done by arranging cells in quantity in the ordinary voltaic battery.

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As regards the knee in the discharge curve, it must be produced by a chemical exhaustion of some sort, either on the positive or on the negative plate, and the knee itself does not tell you as to whether the exhaustion has occurred upon one or upon the other or upon both. I believe that in this particular instance Mr. Edison attributes the knee to the exhaustion of the positive plate, as distinguished from the negative, which simply means that with more of the positive acting substance in that particular pair of elements, the knee would have been deferred beyond the limits of the diagram.

MR. CHAS. J. REED:—It seems to me that it is a very reasonable supposition. We have in this case iron which in oxidizing to the ferrous state would probably give up most of the energy of the cell, and we know that ferrous oxide is easily converted and spontaneously goes over into ferric oxide. The change from ferrous to ferric oxide would not evolve as much energy as the change from iron to ferrous oxide, so that we would get a much lower electro-motive force when the current is developed by the conversion of the ferrous oxide into the ferric than we would before. In the cell which I have mentioned, my own conclusion was that one of those bends or angles in the curve was produced by the exhaustion of material on one plate, and the other by exhaustion of material on the other plate. The materials of each plate in that case seemed to undergo two successive chemical reactions.

MR. H. E. HEATH:=I would like to ask Dr. Kennelly if, from his paper, we should not understand that the chemical or electrolytic action is confined entirely to the active material; because I notice that in the paper it states that the covers for the briquettes are in both plates covered with nickel. Naturally, if there is any electrolytic action then between the nickel and the plates, we should have it at least at the iron plate; but the metals present are all of them in a pure state inert in the solution, and, as nearly as I can understand from the paper, the chemical or electrolytic action is confined entirely to the briquettes and the pure metals present only act as conductors.

DR. KENNELLY:—The gentleman is correct.

MR. STEINMETZ:—I believe we will all agree that this has been one of the most interesting papers which has been presented here for a very long time, and also that all will agree with me when I move a vote of thanks of the INSTITUTE, particularly to Mr. Edison for his kindness in permitting the development of his work to be publicly described before our INSTITUTE; and also a vote of thanks to Dr. Kennelly for having taken the pains and the great interest in our INSTITUTE to prepare this paper and arrange for its presentation. [Carried unanimously.]

DR. KENNELLY:—So far as Mr. Edison is concerned I am sure he will be very gratified to hear of your motion. I can only say that I am more than gratified.

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THE PRESIDENT:—As there seems to be no further discussion, I would like, with your permission, to say a few words before leaving the Chair to my successor.

Neither our old nor our new Constitution gives your retiring President an occasion to address you, and as it is now somewhat late in the evening, I will not take up your time to do so, but I would like to take the present opportunity to thank you once more for having honored me with the presidency during the past year, especially as that year was a somewhat important one for the INSTITUTE, owing to the holding of our first meeting in a foreign country. I also wish to thank you all, especially my colleagues in office, for the many kind courtesies that have been extended to me while in office. It gives me great pleasure to say that the work of the Council during the year has been carried on with complete harmony in every detail. I would like also to express to you my great appreciation and admiration of the excellent and creditable work done by our committees, many of the members of which have worked most energetically and unselfishly in the interests of the INSTITUTE and in many cases at considerable personal sacrifice. That the committees have been successful in most if not all their work, you will no doubt agree with me. Their work was rendered all the more difficult as there were a number of new features in the affairs of the INSTITUTE during the past year, among which may be mentioned our first meeting abroad, which was the beginning of what promise to be very interesting and profitable international associations; the *Conversazione*, which was such a complete success and has given the INSTITUTE considerable prominence; the preparing of the new and much needed Constitution; the successful revival of the annual dinner, which promotes the very desirable social intercourse between the members; our assistance in securing the passage by Congress of the much needed National Bureau of Standards; and last, but by no means least, the munificent gift by Dr. Wheeler, of the very valuable Clark library, accompanied by the generous gift of Mr. Carnegie of equal money value. The good example set by Dr. Wheeler promises to be followed by donations from other members and will hasten very materially the realization of our long felt want of a building and home for our INSTITUTE. All these things have been accomplished by the faithful and energetic work of our committees, and by my colleagues in office, and I take great pleasure in expressing to you my appreciation of their work.

The report of the tellers is now in order.

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TELLERS' REPORT.

NEW YORK, May 21st, 1901.

To the President and Members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Gentlemen:—

The following is the result of the counting of the ballots for the election of officers:

Total ballots received		485
Discarded as follows:		
Ballots bearing no name	23	
Defective ballots	23	
Ballot of resigned member	1	47
Total ballots counted		438

FOR PRESIDENT.

Charles P. Steinmetz	395	T. A. Edison	1
L. B. Stillwell	26	C. O. Mailloux	1
M. I. Pupin	12	Chas. F. Scott	1
C. S. Bradley	1	Wm. Stanley	1

FOR VICE-PRESIDENTS.

Samuel Sheldon	417	Carl Hering	1
George F. Sever	409	C. T. Hutchinson	1
M. I. Pupin	402	J. P. Jackson	1
C. O. Mailloux	8	A. E. Kennelly	1
C. P. Steinmetz	8	Philip Lange	1
B. J. Arnold	6	George P. Low	1
C. S. Bradley	3	R. T. Lozier	1
Louis Bell	2	Wm. Maver, Jr.	1
C. F. Brackett	2	F. A. Pattison	1
J. J. Carty	2	F. A. C. Perrine	1
D. C. Jackson	2	W. L. Robb	1
Herbert Lloyd	1	L. B. Stillwell	1
C. R. Cross	1	W. D. Weaver	1
Louis Duncan	1	S. S. Wheeler	1
I. H. Farnham	1	J. G. White	1
G. H. Guy	1		

FOR MANAGERS.

Chas. F. Scott	427	F. O. Blackwell	1
J. W. Lieb, Jr.	425	J. B. Blood	1
Samuel Reber	412	H. W. Buck	1
W. E. Goldsborough	396	W. C. Burton	1
A. L. Rohrer	5	J. B. Cahoon	1
Eskil Berg	4	H. S. Carhart	1
W. J. Hammer	2	H. C. Cushing, Jr.	1
C. D. Haskins	2	F. B. Crocker	1
D. C. Jackson	2	W. C. L. Eglin	1
H. A. Lardner	2	R. T. Lozier	1
T. C. Martin	2	M. Oudin	1
Townsend Wolcott	2	W. L. Puffer	1
A. H. Armstrong	1	F. B. Rae	1
B. J. Arnold	1	F. S. Smith	1
F. Bedell	1	L. B. Stillwell	1
Louis Bell	1		

FOR TREASURER.

G. A. Hamilton 438

FOR SECRETARY.

Ralph W. Pope	436	W. J. Hammer	1

Respectfully submitted,

EDWARD CALDWELL,
RALPH W. POPE, (Acting)
Tellers.

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THE PRESIDENT:—You have heard the report of the tellers of the election. If no motion to the contrary is made, the report will be accepted and filed. I hereby declare that the following officers have been duly elected for the ensuing year: Chas. P. Steinmetz, President; Dr. Michael I. Pupin, Dr. Samuel Sheldon, Prof. George F. Sever, Vice-Presidents; John W. Lieb, Jr., Charles F. Scott, Prof. W. E. Goldsborough, Col. Samuel Reber, Managers; George A. Hamilton, Treasurer; Ralph W. Pope, Secretary.

Although the term of office of our newly elected President does not begin until after the adjournment of the present meeting, I feel sure that you will overlook the transgression, if I ask him to preside at the closing of this meeting. If there are no objections, I take great pleasure in asking my distinguished successor and highly esteemed colleague, Mr. Chas. P. Steinmetz, to take the Chair. [Applause.]

MR. STEINMETZ:—Gentlemen, I feel highly gratified by the great honor you have conferred on me in electing me your President, and I assure you I shall endeavor to do all that is in my power to come up to the high standard in my presidency which has been set by the President of our INSTITUTE preceding me, and I shall do all that I can to satisfy you and to sustain the standard of the INSTITUTE and increase its importance so far as I shall be able to during the year to come.

I believe the business before the house to-night is completed in an extremely satisfactory manner, if you consider that we have at last succeeded in adopting the new Constitution. I should think, the time being late, that a vote to adjourn would now be in order. The next meeting will be our annual convention.

[Adjourned.]

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THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

has the honor to transmit with

FRATERNAL GREETINGS

to

THE INSTITUTION OF ELECTRICAL ENGINEERS

of Great Britain

the following resolutions:

Whereas, THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, during the visit of its members to London and Paris in connection with the International Electrical Congress of 1900, and also in connection with the joint meeting immediately preceding the same of the British Institution and AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS held in Paris on the 16th day of August, 1900, was the recipient of many courtesies and much hospitality from the British Institution of Electrical Engineers;

Resolved, That THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS herewith respectfully tenders to The Institution of Electrical Engineers of Great Britain its sincere thanks for the many courtesies extended to its members in connection with the above-mentioned visit to London and with the joint meeting of the two Institutions in Paris, both of which have left many pleasureable recollections;

Resolved, That a copy of these resolutions be forwarded to the Institution of Electrical Engineers in London, and that a copy of the same be published in the TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

The above resolutions were unanimously adopted at a meeting of the COUNCIL OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, held in New York City, U. S A., March 22d, 1901.

(Signed) CARL HERING, *President.*

[SEAL.] (Signed) RALPH W. POPE, *Secretary.*

INSTITUTION OF ELECTRICAL ENGINEERS.

Founded 1871—Incorporated 1883.

Victoria Mansions,

28 Victoria Street.

LONDON, S. W., 28th May, 1901.

RALPH W. POPE, ESQ., Secretary

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS,

26 Cortlandt Street, New York City, U. S. A.

Dear Mr. Pope:

The Council has received with very great satisfaction the handsome and generously-expressed illuminated address that your INSTITUTE has been so good as to send to this Institution. They desire us to convey to your INSTITUTE their

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cordial thanks for the address, and to assure your membership that it gave the members of this Institution real pleasure to welcome their American colleagues in London and to join with them in the Paris meeting last year.

The address is to be presented at the Annual General Meeting on Thursday next, and will be shown at our Conversazione in June. To all who took part in our gathering last August it will awaken pleasant memories of much good-fellowship, and will encourage the hope that the bond of international sympathy may grow firmer as years pass by.

We are, Dear Mr. Pope, Yours very truly,

(Signed) JOHN PERRY, *President.*

(Signed) WALTER E. MCMILLAN, *Secretary.*

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

18TH ANNUAL CONVENTION.

NEW YORK AND BUFFALO, AUGUST 14–24, 1901.

New York, Aug. 14, 1901.

The invitations extended to European electrical engineers to attend the 18th Annual Convention of the INSTITUTE at Buffalo, beginning August 20th, were responded to in person by the following gentlemen: Prof. Paul Janet, Director of the Laboratoire Central and of L'Ecole Superieur de l'Electricité, official delegate of the Société Internationale des Electriciens; M. Ch. David Paris; M. J. Courbier, Laboratoire Central de l'Electricité; M. Boy de la Tour, Chief Engineer of Société Fivés-Lille; M. Devauve, standards department Maison Breguet, Paris; M. Marcel Aubert, Ingenieur, Licencié es Sciences; M. Maurice Aubert, Ingenieur, Licencié es Sciences; M. Roux, Ingenieur Civil. All of the above gentlemen are members of the Société Internationale des Electriciens. Herr. F. W. Ch. Janisch, Chief Engineer Siemens & Halske Company, Berlin; Prof. Gustave Gillon, University de Louvain, Belgium; Mr. D. McNaught, Silvertown, England; Mr. Norman C. Sawers, Silvertown, England; Mr. Arthur H. Potts, London, England; Mr. G. H. Cottam, London; Mr. John Denham, Capetown; Mr. A. T. Cooper, Reading, England; Mr. R. L. Gamlin, Kent, England.

As announced in the program, a formal welcome was extended to the foreign guests of the INSTITUTE at the House of the American Society of Mechanical Engineers, 12 West 31st Street, New York City, on August 14th, 1901. President Steinmetz, in calling the meeting to order, expressed his great pleasure in meeting the European engineers who had accepted the invitation to visit the country, and attend the Annual Convention. He invited Chairman Mailloux of the Council Committee to out-

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line the features of the excursions and technical visits which had been arranged for. Upon the conclusion of Mr. Mailloux's remarks, M. Janet, in behalf of the French delegation, warmly expressed in his native tongue, the pleasure experienced by his associates and himself in being able to participate in the proceedings of the INSTITUTE. The members and guests having registered, luncheon was announced, which terminated the proceedings for the day.

On Thursday, August 15th, by invitation of the Crocker-Wheeler Company, the works at Ampere were visited, transportation by special cars being provided by that company. The guests were welcomed upon arrival by President Wheeler and Mr. Dunn. The party returned from Ampere by the 11.43 A. M. train, and reassembled at the Everett House, New York City, where luncheon was arranged for by Chairman Mullin of the Finance Committee. In the afternoon by invitation of the New York Telephone Company, the telephone exchange at 18th street and Irving Place was visited. In this vicinity the excavating for the Rapid Transit tunnel was also inspected.

The International Convention Banquet was held in the evening at the Hotel Marlborough, ninety members and guests with many ladies being present. Past-President Hering presided in the absence of President Steinmetz, while Past-President Martin officiated as Toastmaster. The toasts were responded to as follows: "The Land of Ampere," by M. Janet; "The Countrymen of Faraday," by Mr. N. C. Sawers; "The Successors of Ohm," by Prof. W. Hallock; "The Heirs of Volta," by Mr. Philip Torchio, and "The Legatees of Franklin," by Dr. Schuyler S. Wheeler.

On Friday, August 16th, the party reassembled at the new Edison power-house, foot of 38th Street at the East River. Under the direction of Mr. Calvin W. Rice printed leaflets had been provided giving the technical data of the different power stations which were to be visited. Experienced guides were also at hand in order to give all possible information to the visitors. Through the courtesy of the Brooklyn Edison Company, the New York Edison Company, the Manhattan Railway Company, and the Metropolitan Street Railway Company, the special steamboat "Crystal Stream" had been chartered to convey the party between the different power stations fronting on the East River, and after leaving 38th Street, stops were made at the 76th Street power-house of the Manhattan Railway Company, the 96th Street power-house of the Metropolitan Street Railway Company, the Gold Street station, and the Bay Ridge station of the Brooklyn Edison Company. A bountiful collation was served on board of the boat, while she made a detour around Blackwell's Island in order to permit a more extended view of the approach to New York City from Long Island Sound. For the better accommodation of all, a landing was made at the

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Battery upon the return trip. A party of guests under the guidance of Chairman Mullin and Past-President Hering, went from Bay Ridge to Manhattan Beach for the evening.

No special assignments had been made for Saturday, August 17th, it being necessary that personal preparations should be made for the Buffalo trip.

On August 18th, the steamboat "Montauk," which had been chartered by the Transportation Committee, awaited the party at the foot of 43d Street, North River. The outlook was gloomy as a brisk rain was falling at 9 A. M., the hour fixed for departure. It was half-past nine when the boat started, with about 140 people on board. The rain soon ceased, and although the sun failed to shine, the air was clear, and the trip up the Hudson was most enjoyable, the cuisine as usual being carefully looked out for. Upon arrival at Albany about eight o'clock P. M., special electric cars conveyed the party to the Hotel Ten Eyck, where all were made comfortable for the night. Monday morning at half-past eight o'clock, the party boarded the special train, which pulled out of the Union Station over the New York Central Railway. The train landed its passengers inside the yard of the General Electric Works at Schenectady, and every opportunity was afforded the visitors for a thorough examination of this great establishment. An efficient corps of guides had been provided, and no restrictions were enforced. Carriages had been provided for the entertainment of the ladies, and while they were being driven about the city and vicinity, the gentlemen made a tour of the factory. At noon the entire party reassembled in one of the new shops, where a fine luncheon was served, presided over by Vice-President Rice of the General Electric Co. At one-thirty P. M. the party again boarded the train, which was in waiting, and a quick run was made to Buffalo, that city being reached about eight P. M. Most of the party went to the Niagara Hotel, which had been selected as the headquarters during the Convention.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Eighteenth Annual Convention.

Buffalo, N. Y., August 20, 21, 22, 23, 24, 1901.

Tuesday, August 20.

President Charles P. Steinmetz called the Convention to order at 11 A.M., in the Assembly Room of the New York State Building, at the Exposition grounds.

President Steinmetz:—As President of the American Institute of Electrical Engineers, I herewith open the second session of the Annual Convention. Accepting the very kind invitation extended to us, we have assembled here at the New York State Building, on the grounds of the Pan-American Exposition, to carry on our work, consisting in the reading and discussion of papers, in scientific and social conversation, and incidentally to take part in some entertainment.

Before proceeding with any regular program I will call for a few words from Prof. George F. Sever, who has been so intimately connected with the success of the Pan-American Exposition and its electrical features, which, as we all know, are the most prominent and the most important at the Exposition.

Prof. George F. Sever:—Mr. President and members of The American Institute of Electrical Engineers and their distinguished guests, I bid you a hearty welcome to the Pan-American Exposition. It is certainly very gratifying to see this distinguished body of electrical engineers present at this magnificent Exposition, and I can only say: Here it is. Take it. Investigate it. Most of it, of course, is nailed down, but the illumination you can carry away in your minds and forever call your own. The buildings devoted to the exhibits are by no means as large as were those at Chicago and at various other expositions, but we feel that they contain articles of great merit, and illustrating the very latest advances in all lines of art, industry

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and science. Those of you who have seen the illumination of the buildings and grounds and the other details, certainly can appreciate the magnificent work that has been done by the engineers connected with the Exposition.

I hope you will make free use of the engineers of the Exposition so far as they can be of service to you in the giving of information. We are perfectly ready and willing to do what we can. The electrical exhibitors in the Electricity Building have placed their services at your disposal in order to guide you about the grounds and to show you details which you might find it difficult to learn about. The office of the Superintendent of the Electrical Exhibits you can count upon as your headquarters in case you desire any knowledge or information pertaining to the Exposition.

I appreciate the opportunity of appearing before you and welcoming you to this magnificent Exposition, and I trust that your stay here will be most pleasant and fully up to the expectations which you have had in mind.

PRESIDENT STEINMETZ:—I believe I voice your sentiments in thanking Prof. Sever heartily for the kind welcome he has extended to us, and I have not the least doubt but that his hopes will be realized; that we shall feel very gratified and very satisfied with all that we see here, and not only that, but that we shall carry away with us pleasant recollections and the benefit of a decided advance in our intellectual and scientific development.

The Secretary made some announcements, and the Convention then adjourned to August 21st.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 21st, 1901, President Steinmetz in the Chair.

SYNCHRONISM AND FREQUENCY INDICATION.

BY PAUL M. LINCOLN.

I.—Synchronism Indicator.

It has long been recognized that the operation of paralleling alternators makes desirable the use of some more sensitive method than the usual synchronizing lamps so extensively employed in the past, and which are to-day most generally used for indicating synchronism. The obvious lack of sensitiveness on the part of lamps, when used for synchronizing, has led in many cases to the substitution of voltmeters, with a considerable improvement in the accuracy of the indications. There is still, however, much to be desired on the score of sensitiveness in indicating the point of synchronism, and this point is one which is becoming more and more important as the size of alternators become larger and their regulation stiffer.

The synchronism indicator described in the following pages is new, so far as the writer is aware, and he trusts that its analysis may be of interest to the members of the Institute.

Suppose a stationary coil F has suspended within it a coil A, free to move about an axis in the planes of both coils and including a diameter of each. If an alternating current be passed through both coils, A will take up a position with its plane parallel to F. If now the currents in A and F be reversed with respect to each other, coil A will take up a position 180° from its former position. Reversal of the relative directions of currents in A and F is equivalent to changing their phase relations by 180°, and therefore this change of 180° in phase relations is followed by a corresponding change of 180° in their mechanical relations.

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Suppose now that instead of reversing the relative direction of currents in A and F, the change in phase relations between them be made gradually and without disturbing the current strength in either coil. It is evident that when the phase difference between A and F reaches 90° the force between A and F will become reduced to zero and a movable system, of which A may be made a part, is in condition to take up any position demanded by any other force. Let a second member of this movable system consist of coil B, which may be fastened rigidly to coil A, with its plane 90° from that of coil A, and the axis of A passing through a diameter of B. Further suppose a current to circulate through B, whose difference in phase relative to that in A, is always 90°. It is evident under these conditions that when the difference in phase between A and F is 90°, the movable system will take up a position such that B is parallel to F, because the force between A and F is zero, and the force between B and F is a maximum; similarly when the difference in phase between B and F is 90°, A will be parallel to F. That is, beginning with a phase difference between A and F of 0, a phase change of 90° will be followed by a mechanical change in the movable system of 90°, and each successive change of 90° in phase will be followed by a corresponding mechanical change of 90°. To investigate the mechanical relations corresponding to intermediate phase relations, suppose the phase difference between A and F to be 0. The force between A and F will then be a maximum, and that between B and F, 0. Now suppose a small change in phase between A and F to take place. The force between A and F becomes slightly less than the maximum, and that between B and F becomes other than 0. The movable system will take up the position of equilibrium between forces on A and B, which will be somewhere intermediate between A parallel to F, and B parallel to F. It is further evident that the direction of motion of the movable system depends upon the sign of the differential change, so that such a device is not only responsive to a change of phase between A and F, but is also responsive to the direction of that change.

It may be interesting to note that quadrature between A and B is not absolutely necessary either in the mechanical angle between A and B, or in the phase angle between their currents. So long as there is a displacement between A and B, both mechanical and electrical, the device is responsive to phase changes between A and F.

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The above is a brief description of the principles upon which rests this new synchronism indicator. Connect coil F to a set of bus bars, and coils A and B to a dynamo that is to be paralleled to those bus bars and in the motion of movable coils, there is a constant index of the phase condition of the dynamo with respect to the bus bars. Fig. 1 shows a photograph of a synchronism indicator built on the above principles and installed in the power-house of the Niagara Falls Power Company, where it has been in successful operation for some time. This instrument is mounted on a swivel so that it can be made to face any one of the dynamos to be synchronized by its use. This mounting makes

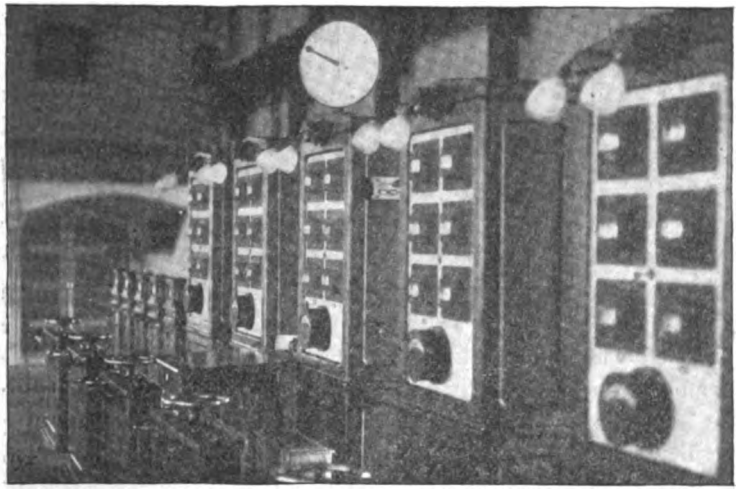

FIG 1.

it possible for the attendant handling the paralleling switch, as well as the one who controls the speed of the dynamo, to see the instrument, and be fully informed as to the condition of the dynamo with respect to synchronism.

In the construction of the device shown in Fig. 1, a laminated iron magnetic circuit is used and the phase difference between A and B is secured by using a non-inductive resistance in series with one coil, and an inductance in series with the other. It is of course impossible to secure 90° phase difference in this manner, but sufficient difference can be obtained to answer all practical purposes. Current is introduced

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into the armature through three slip rings, one of the rings being made to do duty for one end of both armature windings.

The ideal synchronizing device should perform three functions.

1. It should tell the amount of difference in frequency.

2. It should tell whether the machine being synchronized is running too fast or too slow.

3. It should tell the exact point of synchronism.

Comparing the above described device with devices now ordinarily in use for the purpose of synchronizing, in regard to these criteria, we find :

1. In regard to the first point, no difference obtains.

2. In regard to the second point, the new device gives complete information, while ordinary devices give none.

3. In regard to the third and most vital point, usual devices give only partial information, while that given by the new device is complete not only at the point of synchronism, but at every other point in the cycle.

The experience of the Niagara Falls Power Company with this new synchronizer has been most gratifying. The average time required to synchronize a dynamo has been divided by at least two, and the incipient welding of switch contacts which occasionally occurred with the old method of synchronizing, due to dynamos going in slightly out of step, has been entirely obviated. The switchboard attendant seems to feel, when synchronizing a dynamo, a degree of confidence which was impossible under former conditions.

It may be of interest to derive an expression giving at all points in the cycle the exact relations between mechanical and phase angles in such a device as is above described. It will also be of interest to determine the behavior of the device when the electrical and mechanical angles between A and B are other than 90° and other conditions to be mentioned later.

In Fig. 2 let F F be the plane of the field, O A the plane of armature coil, A and O B the plane of armature coil B. In the discussion hereafter θ will always represent the mechanical angle between F F and O A and φ will always represent the electrical angle between their currents.

We shall assume

I. That the electrical angle between the currents in O A and O B is 90°.

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II. That the mechanical angle between windings of A and B is 90°.

III. That the ampere turns in A and B are equal.

IV. That the current in armature element A is in phase with its E.M.F.

V. That the E.M.F. produced in the armature windings by the field and vice versa is neglible.

VI. That the E.M.F. wave produced by the rotation of the armature in the field is a sine wave.

VII. That the waves impressed upon the device are sine waves.

With these assumptions we have force on A as,

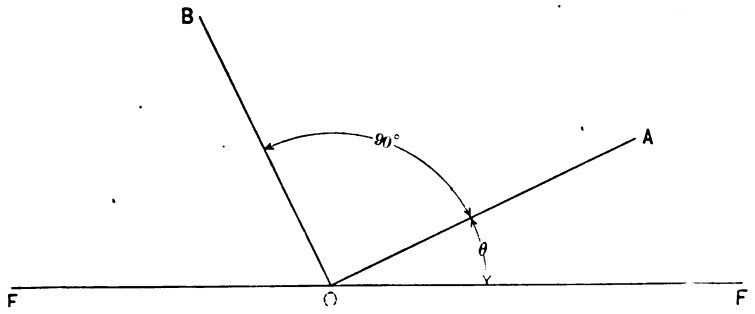

FIG. 2.

(1) $F_1 = K \sin\theta \cos\varphi$, and the force on B is

(2) $F_2 = K \sin(\theta + 90^0) \cos(\varphi \pm 90^0)$, whence

(3) $F_2 = \pm K \cos\theta \sin\varphi$.

For equilibrium $F_1 + F_2 = 0$, whence

(4) $\sin\theta \cos\varphi = \pm \cos\theta \sin\varphi$

(5) $\tan\theta = \pm \tan\varphi$

(6) $\theta = \pm\varphi$ or $\pm(\varphi + 180^0)$

The double signs indicate that the direction of rotation of θ with respect to φ depends upon the sine of the angle between the two armature currents. The two values 180° apart indicate two points of equilibrium in the cycle. One of these is evidently a point of unstable equilibrium.

If now the electrical angle between the two armature wind-

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ings is other than 90°, the above will be modified as follows,

Force on A is:

$$F_1 = K \sin \theta \cos \varphi \tag{7}$$

and force on B is:

$$F_2 = K \sin (\theta + 90^0) \cos (\varphi \pm \beta) \tag{8}$$

Where β is the electrical angle between the currents in the two armature windings.

For equilibrium:

$$\tan \theta = \pm \sin \beta \tan \varphi - \cos \beta \tag{9}$$

From this it is seen that when $\varphi = \pm 90°$, $\theta = \pm 90°$, and when $\varphi = 0°$ or $180°$, $\theta = \beta - 90°$ approximately, that is, so long as β does not depart largely from 90°. It is also evident that the maximum difference between θ and φ occurs close to the point $\varphi = 0°$ or $180°$.

Under these conditions, therefore, the maximum departure from equality between θ and φ occurs when φ is nearly zero and amounts practically to the amount the electrical angle between the two armature currents departs from 90 degrees.

Differentiating (9) we get:

$$\frac{d\theta}{d\varphi} = \pm \sin \beta \frac{\cos^2 \theta}{\cos^2 \varphi} = \frac{\cos^2 \theta \cos^2 \beta \pm 2 \sin \theta \cos \theta \cos \beta + 1}{\sin \beta} \tag{10}$$

Which is an expression for the sensitiveness of the device. That is, if the electrical angle is varying at a constant rate, the above expression gives the rate at which the mechanical angle varies. An inspection of the above expression shows that supersensitive and subsensitive points exist on diameters at about the points $\theta = \pm 45°$.

The exact points of super- and subsensitiveness are

$$\theta = \tan^{-1} \frac{\cos \beta}{2} \pm \sqrt{1 + \frac{\cos^2 \beta}{4}} \tag{11}$$

The effect of these super- and subsensitive points is to cause an acceleration and retardation of the synchronizer indicator hand at certain points in the phase cycle even when the phase change is taking place at a perfectly even rate.

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If desired, however, this variation due to departure of electrical angle from ninety degrees may be completely compensated for by adjusting the mechanical angle between the two armature windings so that it is equal to the supplement of the electrical angle between their currents. Proof of this is as follows:

Force on armature winding A is

$$F_1 = K \sin \theta \cos \varphi$$

and force on armature winding B is

$$F_2 = K \sin (\theta + \alpha) \cos (\theta \pm \beta)$$

Where α is the mechanical angle between the two armature windings and β is the electrical angle between their currents.

For equilibrium

$$\sin \theta \cos \varphi = - \sin (\theta + \alpha) \cos (\varphi \pm \beta) \tag{12}$$

For purpose of simplifying take $\theta_1 = \theta + \alpha$.

Substituting and expanding we have

$$\sin \theta_1 \cos \alpha \cos \varphi - \cos \theta_1 \sin \alpha \cos \varphi = - \sin \theta_1 \cos \varphi \cos \beta \pm \sin \theta_1 \sin \varphi \sin \beta \tag{13}$$

By making $\alpha = 180^\circ - \beta$, this becomes

$$\cos \theta_1 \cos \varphi = \pm \sin \theta_1 \sin \varphi \quad \text{whence} \tag{14}$$

$$\theta = \pm (\varphi + \alpha \pm 90^\circ) \tag{15}$$

From this it appears that the difference between the mechanical and electrical angles is always a constant when the mechanical angle between the two armature currents is made equal to the supplement of the electrical angle between their currents, provided the ampere turns in the two armature elements are equal.

Now to consider the result of making one of the armature windings stronger than the other. Supposing other conditions to remain as per our assumptions on page 259 we have force on winding A is

$$F_1 = K_1 \sin \theta \cos \varphi \quad \text{and force on B is} \tag{16}$$

$$F_2 = K_2 \cos \theta \sin \varphi \tag{17}$$

When equilibrium exists:

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$$K_1 \sin\theta \cos\varphi = K_2 \cos\theta \sin\varphi \tag{18}$$

$$\tan\theta = \frac{K_2}{K_1} \tan\varphi \tag{19}$$

Whence

$$\frac{d\theta}{d\varphi} = \frac{K_1}{K_2} \sin^2\theta + \frac{K_2}{K_1} \cos^2\theta \tag{20}$$

From this it appears that at and near the diameter 0°–180° the device is supersensitive, and subsensitive at and near the diameter + 90° to — 90°, when $K_2 > K_1$.

If $K_1 > K_2$ the super- and subsensitive points are reversed. It is further evident that super- and subsensitive points may be made to occur at any desired point in the cycle by a combination of the methods above cited.

For the purpose of a synchronism indicator it is usually preferable to dispense with any supersensitiveness at the point of synchronism for the reason that supersensitiveness at any point tends to give the indicating hand a jerky motion, setting up vibration of the armature across the point of equilibrium.

II.—Frequency Indicator.

The problem of frequency measurement is one which has from time to time attracted the attention of experimenters and designers as a result of which a number of different devices have been proposed and tried with more or less success. My excuse for adding one more to the number of devices proposed for this purpose is that the device herein described not only gives a beautiful theoretical solution of the problem, but also bears out its promise in actual practice so far as it has been tried.

It may seem somewhat peculiar to describe in a single paper two so dissimilar devices as a synchronism indicator and a frequency indicator. The reason for this is that the two devices were conceived and developed almost simultaneously and are very similar to each other in principle and design. One was, in fact, a direct development of the other.

The synchronism indicator described in the first part of this paper is in reality a phase meter, in that it gives a continual indication of the phase relations between the currents in its field and armature. If now the current in one of these elements can be made to change its phase with reference to that in the other,

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due to a change in frequency, the device will evidently become a frequency indicator.

This result can be effectually obtained by inserting a capacity in series with the inductance of the field. The phase relations between the E. M. F. and currents in the armature remain practically unchanged with varying frequency while under the above condition; that between the E. M. F. and current in the field, plus the added capacity, is sensitive to frequency change. The angu-

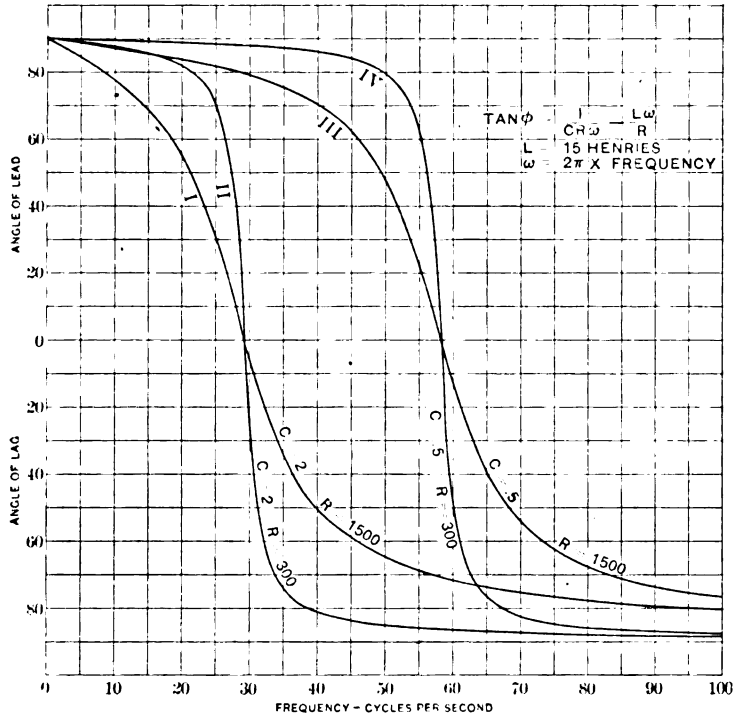

FIG. 3.

lar position assumed by the armature is an indication of the phase relation between currents in field and armature, and is therefore a measure of frequency. Assuming then that an angular movement of the armature always represents an equal angular shift of phase between currents in it and the field, it is only necessary to determine the phase change in the field for a given frequency change to obtain a complete calibration of this frequency indicator.

Fig. 3 gives for a number of different conditions, the relations

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between frequency and phase angle in circuits containing inductance, capacity and resistance. These curves show that the most rapid change of phase angle for a given frequency change occurs at the point where the phase angle is 0.

When phase angle is 0, resonance exists; that is the capacity ohms at that point are equal to the inductive ohms. It will be interesting to determine how great a frequency change is indicated by a given phase angle change both at the point of resonance as well as at other points in the cycle.

The relation between phase angle and frequency is given by

$$\tan \varphi = \frac{1}{C R \omega} - \frac{L \omega}{R} \tag{21}$$

In which

φ = phase angle.

L = inductance in henrys.

C = capacity in farads.

R = resistance in ohms.

ω = $2 \pi \times$ frequency in cycles per second.

The sensitiveness of the instrument is the ratio of the phase change which takes place for a small frequency change and expression for sensitiveness may be obtained by differentiating (21)

$$\frac{d \varphi}{d \omega} = - \cos^2 \varphi \left(\frac{1}{C R \omega^2} + \frac{L}{R} \right) = \frac{C R (1 + C L \omega^2)}{(1 - C L \omega^2)^2 + C^2 R^2 \omega^2} \tag{22}$$

Resonance occurs when

$$\omega^2 = \frac{1}{C L}$$

and if this value be substituted in (22) it becomes

$$\frac{d \varphi}{d \omega} = - \frac{2 L}{R} \tag{23}$$

This is the expression for sensitiveness at the point of re-

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sonance, at which point it reaches a maximum. The angular change in degrees for a 1% change in frequency at resonance is

$$\frac{7.2\ L\ n}{R}$$

in which n is frequency in cycles per second.

The usual service required of a frequency indicator is the measurement of the small variations from normal frequency or speed which take place under ordinary operating conditions. For this purpose the instrument herein described is peculiarly well adapted. The capacity and inductance in the field circuit, both of which are capable of accurate measurement, can be so chosen that resonance is produced at normal frequency. That is, they should be chosen so as to satisfy the equation

$$(2\ \pi\ n_0)^2 = \omega_0^2 = \frac{1}{C\ L}$$

where n_0 is the normal operating frequency. The instrument will under these conditions be used at a point where its sensitiveness is a maximum.

Sensitiveness, however, is not the only requisite in the design of a frequency indicator. Its range is a matter which deserves a share of attention. Considering (21) it is evident that when $\omega = 0$, $\varphi = +\ 90°$, and when $\omega = \infty$, $\varphi = -\ 90°$. All frequencies of positive sign are therefore included in this total range of 180°. Of this total range, however, only in that portion between the limits

$$\varphi = \tan^{-1} \pm \sqrt{\frac{L\ \omega_0}{L\ \omega_0 \pm R}} \tag{24}$$

is the sensitiveness above one-half the maximum. The corresponding limits for the frequency are given by

$$\omega = \sqrt{\omega_0^2 \pm \frac{R}{L}\ \omega_0} \tag{25}$$

That portion of the scale between these two limits may be taken as the working range. This working range occupies approximately 90° of the scale extending from approximately plus 45° to

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minus 45°. The frequency included between these two limits is approximately expressed by

$$\frac{R}{2\pi L}$$

As might be expected the expressions for sensitiveness and range are reciprocal quantities; as one increases the other decreases.

So far we have been proceeding on an assumption of the use of a perfect phase meter; that is, one whose phase angle changes are exactly reproduced by mechanical angle changes the same in amount.

Methods of obtaining super- or subsensitive points of mechanical angle, change with respect to phase angle change are given in the first part of this paper. These methods are as applicable to this frequency meter as the synchronism indicator. For instance, suppose it is desired to carry sensitiveness at the point of resonance to a point beyond the possible limits of

$$\frac{2L}{R}$$

This can evidently be accomplished by diminishing that armature current whose phase nearest coincides with that of the field current. By this means sensitiveness may be carried to any limit desired.

By certain modifications an instrument may be made to possess the double advantage of long range and extreme sensitiveness. Adjust an instrument to extreme sensitiveness at resonance by properly fixing the ratio of the two armature elements. Now by placing in series with the field an adjustable capacity or an adjustable inductance, or both, the normal frequency to be measured may be brought within the comparatively narrow range of the instrument, and the frequency to which the instrument is adjusted may be found by noting the values of inductance and capacity in circuit. Or we can go a step further and omit entirely that armature element which is in phase with the impressed E. M. F. Then by adjusting the inductance and capacity in the field circuit so that there is no torque exerted on that armature element whose current differs by ninety degrees from the E. M. F. impressed on the

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field, the frequency of the impressed E. M. F. is measured directly by

$$\sqrt{\frac{1}{C\,L}} \times \frac{1}{2\,\pi}$$

In applying this device to the frequency measurements of a power or lighting circuit, the most natural method of obtaining the phase difference required by the two armature elements, is to connect a non-inductive resistance in series with one of them and an inductive resistance in series with the other. Although it is impossible by this method to reach a phase difference of 90°, it can be nearly enough approximated to answer every purpose. There is one advantage which pertains to this method of obtaining the phase difference between the armature elements. The current in the inductive element is inversely proportional to frequency, and since sensitiveness at the point of resonance is directly proportional to this ratio, the expression (23) becomes

$$\frac{d\,\theta}{d\,\omega} = -\frac{2\,L}{R}\,\frac{\omega_1}{\omega} \tag{26}$$

and the instrument's indication in degrees for a one per cent. change of frequency becomes

$$\frac{7.2\,L\,n_1}{R} \tag{27}$$

n_1 and ω_1 are here the frequency and angular velocity at which the currents in the two armature elements are equal. Advantage lies in the fact that the expression (27) is independent of frequency.

The device is evidently applicable to the measurement of the speed of any rotating body by attaching thereto a small alternating current dynamo. By making the dynamo two-phase, the proper phase relation for armature elements of the meter can be easily obtained. One advantage of using this style of meter is that its indications are dependent only on the frequency of impulses transmitted thereto, and are independent of the voltage applied, so long as it is sufficient to operate the instrument.

It may be interesting to enumerate the most apparent advantages of frequency or speed indicator such as has been described.

1. First its point of greatest sensitiveness comes at the point of normal speed or frequency at which point it is, as a rule, most desired.

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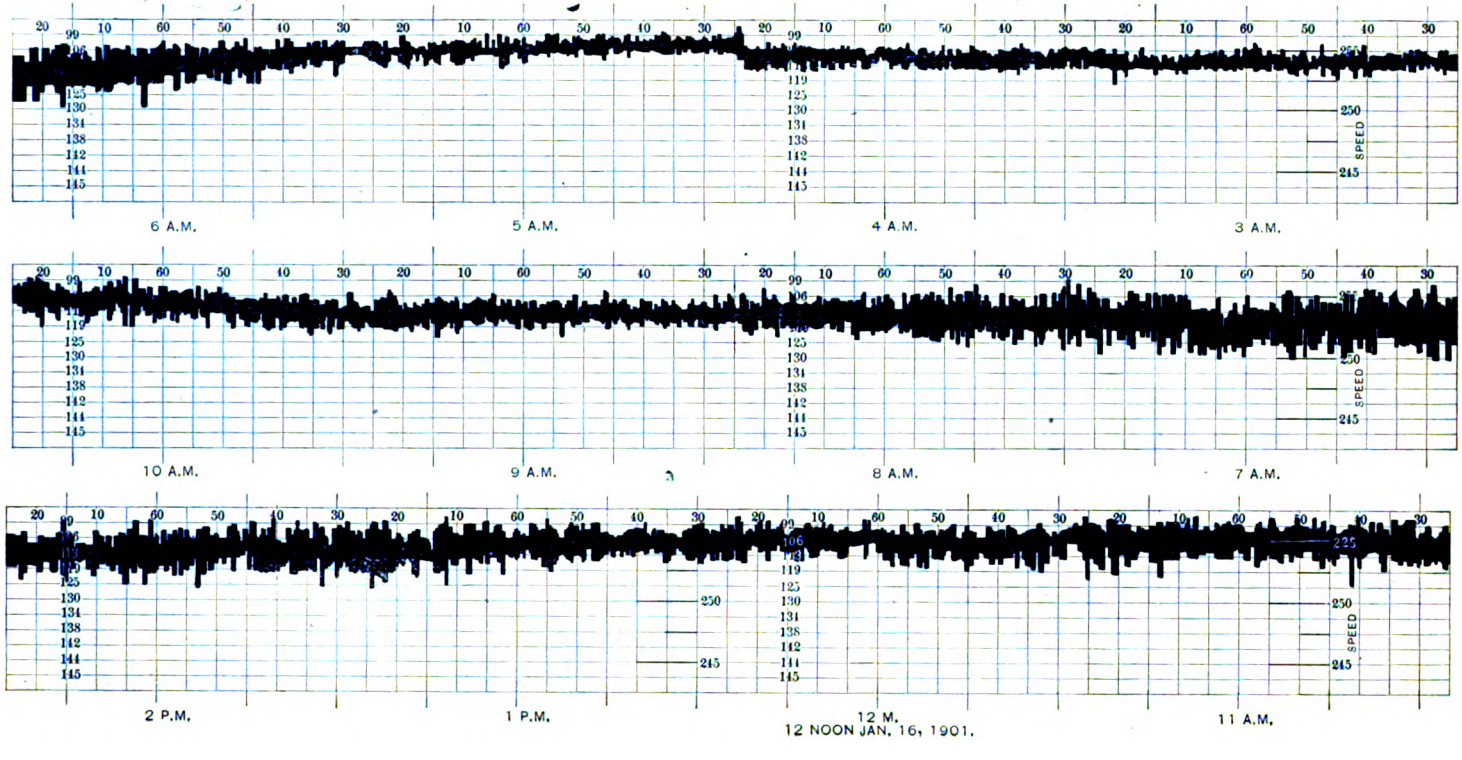

Fig. 4.

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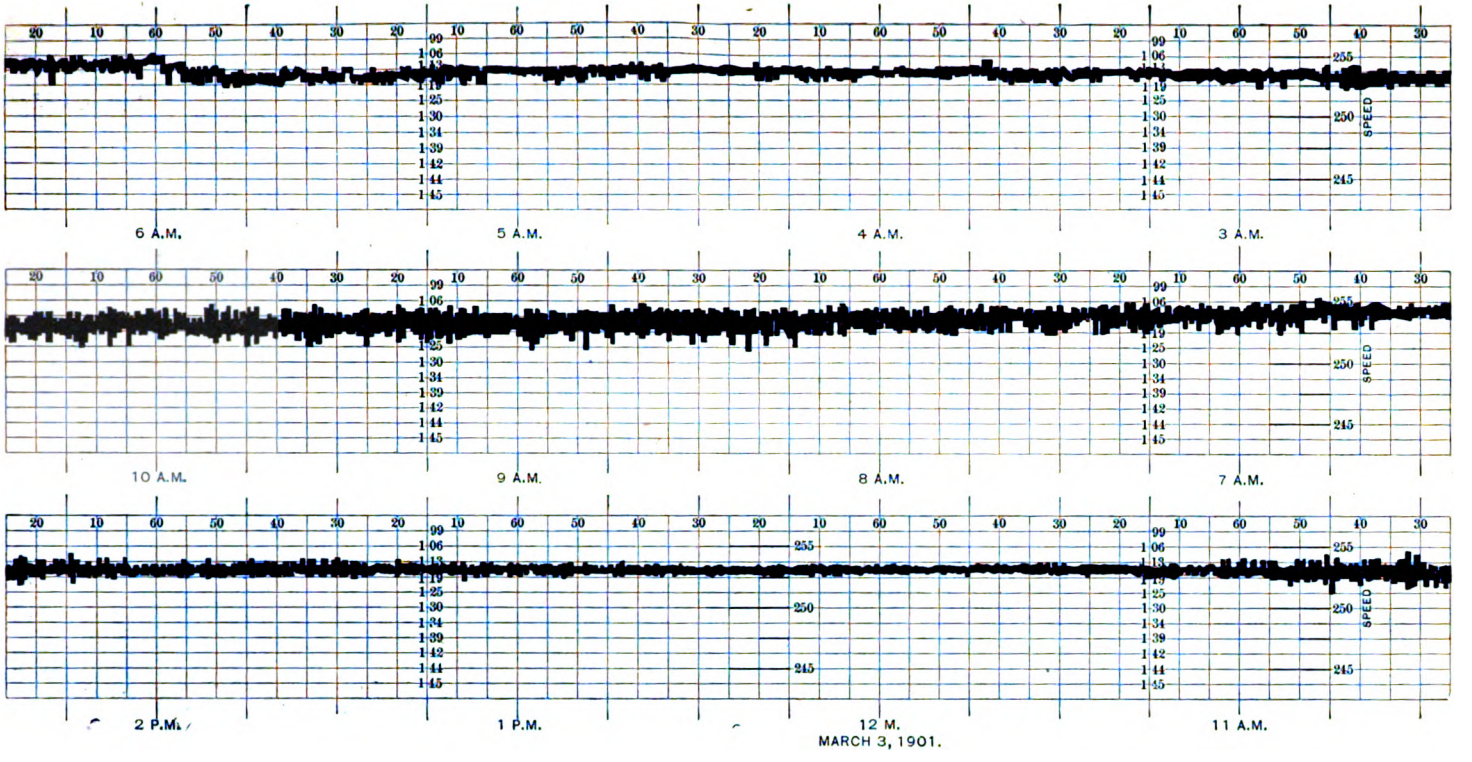

FIG. 5.

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2. The point of normal frequency may be made adjustable by including in circuit an adjustable capacity or inductance.

3. The point of normal frequency may be predetermined by electrical measurements.

4. It may be made general in its application as a speed indicator by the addition of a small A. C. dynamo.

5. It may be placed any desired distance from the body whose speed of rotation it is desired to measure.

The condition which originally led to the design of this apparatus was the complaint made to the Niagara Falls Power Company by its distributing agent in Buffalo, The Cataract Power and Conduit Company, that there occurred at times an undue fluctuation of speed.

The tachometers at that time used by the Niagara Falls Power Company were not sufficiently sensitive to indicate the fluctuation complained of. A recording tachometer was obtained and put into service. This recording instrument depended on centrifugal force for its action, but its sensitiveness was far too small to measure the fluctuations we wished to record. A conception of the instrument described above occurred to the writer. An instrument was made up, a pen was attached to its armature and it was set to recording the frequency fluctuations on the Buffalo circuit where it has been doing successful duty ever since. So far as the writer is aware it is the first instrument of its kind ever made, and its success has induced the writer to give a description of it to the INSTITUTE.

A few sample speed records as made by this instrument may be of interest. Figure 4 shows a speed record made on January 16, 1901. At first glance the speed fluctuations seem to be severe, but when it is remembered that each horizontal line represents a speed change of only one half per cent. and that the speed curve is that of a water-driven dynamo operating on a load largely composed of street railway service, engineers familiar with the difficulties will undoubtedly agree that the results obtained are above the average.

The very considerable improvement exhibited between the chart of January 16th, 1901, and that of March 3, 1901, [Fig. 5] is in a large measure due to the existence of a continuous speed record giving an opportunity to note the most efficient governor adjustments.

PRESIDENT STEINMETZ:—Gentlemen, regarding the discussion it has been decided that we shall not have separate discussions of each paper, but first read all the papers dealing with similar subjects, and then have a discussion of them jointly. In pursuance of this arrangement I now call on Mr. Caryl D. Haskins to read his paper on "Some Fundamentals of Electric Meters." I may add that one of the papers which was intended for to-morrow, the paper on "Power Factor Indicators," by Mr. W. H. Browne, Jr., will be read to-day, as dealing with a subject very closely allied to to-day's subject.

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A paper presented at the 10th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 21st, 1901. President Steinmetz in the Chair.

SOME FUNDAMENTALS OF ELECTRIC METERS.

BY CARYL D. HASKINS.

In preparing for presentation to the INSTITUTE my third paper on the general subject of recording meters, I have found it somewhat difficult to sift out from the vast mass of details a very few of the most vital considerations in construction and operation, which seem chiefly to merit consideration and discussion at your hands. It is the mass of individually trivial details which to-day constitute the chief field of study and investigation in electric metering.

The broader and more basic characteristics of the art have been widely discussed long since. Like the whole field of electrical engineering, recording meter design has progressed rapidly. A very few years ago our attention was given to such general issues as how to make a meter that would register on a dial, or how to make a meter that would not necessitate the winding of a clock, or how to make a meter that would record with tolerable accuracy through a range somewhat better than 4 to 1. To-day the art has reduced itself to what might be termed "A microscopic study of trivialities" purposed to gain such improvements as a few years since would have been regarded as academic; as, for example, better behavior on variations of wave form, an increase of 1% or less in average accuracy on loads of from 1% to 5% of the meter's rating, the maintenance of straight line accuracy on loads having power factors substantially unheard of commercially a few years ago, and the like.

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This last consideration, that of accuracy on inductive loads, is one of the greatest importance, and has probably not received as much attention at the hands of meter engineers as it merits. I have not chosen to deal with it to-day, because it has been my desire in preparing this paper to lay a very few essentials before you in a thoroughly analytical manner.

To properly deal with meter accuracy under inductive loads, a paper should be devoted to this subject alone, and the subject would necessarily confine one to the consideration of alternating current meters only, a limitation which I by no means wish to accept.

Accuracy on inductive loads is unquestionably an absolute essential for all meters destined for use on alternating circuits carrying any other loads than incandescent lamps, but the elaboration of this topic before you to-day belongs more properly to my colleagues than to me.

I have chosen for my theme perhaps the most important of the considerations which are to-day engrossing the attention of meter engineers—namely, the relation between torque, friction, aging of various kinds and local surroundings. These four factors constitute the chief governing conditions in connection with meter accuracy, on loads of less than 20% of the meter's average rating. These considerations are, of course, confined to the typical motor meter. We have, however, long since come to regard the motor type of meter as the only electrical integrating device capable of being manufactured at a cost rendering it a commercial possibility, whilst retaining the degrees of reliability, convenience and accuracy demanded by the American market. It may indeed be fairly said that the considerations I have selected are the dominant ones in the American meter art. Substantially all of the motor meters known to the American market have a straight line law within their limitations, if friction be eliminated from consideration.

The limitations are, I admit, somewhat severe, but I am probably entirely safe in saying that the electricity meter, as the American purchaser receives it, is subject to a straight line law on non-inductive loads of the frequency, wave form and potential for which it has been calibrated.

Unfortunately friction cannot be eliminated, but its effect on accuracy may be minimized to a remarkable degree.

There is relatively little difficulty in producing a recording meter in which the effect of friction on accuracy is negligible,

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even to a degree which may defy detection, at the time the meter issues from the laboratory. But friction causes are manifold and elusive, and I doubt if I overstate the mechanical situation when I say that a meter having the least evidence of friction in its initial condition may, at the end of a period of use, show more error due to friction and consequent light load error than other meters which had much more initial friction.

This is the abstract problem which lies before the engineer, and it has been met by numerous alternatives, all more or less effective.

Taking the next step in the analysis of the situation, we note that the motor element of a recording meter does two kinds of work: First, the driving of a dynamo in the form of a foucault current disk, or the equivalent—which is the work contemplated in the meter's theoretic law. The ratio of this work does not vary, provided the permanent magnets are literally permanent, except under physical conditions which can easily be provided for and guarded against. Second, friction work not contemplated in the theoretic law, and therefore tending to distort the accuracy curve.

Friction is relatively unobjectionable so long as it remains a constant value, for as a constant value it can be readily compensated. The meter having X friction can scarcely be regarded as better than the meter having 10 X friction, provided these values do not change with time or load, a condition which we cannot unfortunately find in practice.

In seeking the alternative remedies for this condition three courses of study present themselves to us: The minimizing of friction as an individual study, means for increasing friction compensation with increase of friction, and finally, the radical increase of foucault current load in relation to possible friction load.

The two latter alternatives have always presented themselves to me as the most promising.

The dissipation of a relatively very large amount of energy in the foucault current disk renders wide variations of friction substantially negligible. In other words, if we can make the work contemplated in the law of the meter a large value, then the variations of work not contemplated in the law become insignificant in relation to the whole work. This means that we must dissipate in the foucault current disk the largest possible

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amount of energy consistent with economy. This statement, translated into practical terms, means permanent magnets of the greatest possible strength and a foucault current disk of the greatest possible conductivity consistent with the physical limitations.

The whole essence of success in a motor meter necessarily lies in literally permanent magnets. Since it is vastly easier to make a weak permanent magnet than a strong one, the temptation to get along without the dissipation of a maximum amount of energy in the disk is very great.

If one could make only very weak damping magnets, and therefore dissipate in the foucault disk a very small amount of energy, it would naturally become necessary to get initial friction very low to secure initial accuracy, and in doing this there is always grave danger of sacrificing a permanent minimum of friction to a temporary minimum of friction.

At this point the meter engineer must, if he is to follow the right path, become a physicist, a metallurgist, and, in some measure, a chemist; for he must make a deep and consistent study of strong permanent magnets, which involves a careful investigation of the chemical and physical properties of steel, and of the best means for introducing the initial magnetism, and of reducing this initial magnetism to the largest permanent residue that the magnet can be relied upon to retain. The shaping of the permanent magnets is also of the very greatest importance. How important you probably realize, for this subject has already been carefully dealt with in a most able essay by Dr. Kennelly.

Certain recording meters use a copper foucault disk in place of the more common aluminium disk. With a copper disk of a given thickness, moving at a given speed, more work can be expended in the generation of foucault currents with a magnet of given strength than with any other metal commercially possible. To substitute an aluminium disk having the same peripheral speed and the same thickness, means either to decrease the total work in the disk or to increase the strength of the permanent magnets. The latter is a desirable alternative which can possibly be achieved. The former is a highly undesirable alternative, for reasons which I have stated.

On the other hand, to substitute an aluminium disk of the same conductivity and purposed to rotate at the same speed as

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the copper disk, it is necessary to increase the thickness of the disk. This means that the jaws of the magnets must be further separated, if the clearances have already been reduced to a minimum. This, in its turn, means less density in the permanent magnets and less drag or load.

I have mentioned these tributary considerations to show the conditions which surround the work of the engineer whose purpose is to design a meter which shall expend a maximum proportion of total work in the foucault disk, and to show the chief danger in this direction of effort—namely, that of resorting to a magnet which may not be permanent.

Having achieved a meter mechanism in which the work expended in rotating the foucault disk is relatively high, and having constructed a mechanism in which the *changes* of friction are a minimum, rather than a mechanism in which *initial* friction is a minimum, it is next necessary to provide means for immediately offsetting external conditions, which exert a modifying effect upon the friction value.

In the earlier days of meter operation it was regarded as desirable to reduce friction periodically to as nearly its initial value as possible by cleaning and the like.

It may be regarded as an axiom that friction will increase with use. This increase may be large or small in relation to the whole friction dependent upon design, and it may be large or small in relation to the total work of the meter, dependent largely upon the amount of work expended in the foucault disk.

All friction, however, as well as friction increases, is tributary to and governed by the conditions surrounding installation, and the chief of these external influences is vibration, though the literal results of time, consequent corrosion, etc., as well as changes of temperature, play their part.

The effect of vibration on the work value of friction is great, for perfectly obvious physical reasons, and this effect of vibration on friction becomes more prominent as the friction value increases in relation to total work.

It is, therefore, not sufficient that friction should be neutralized by compensation at an average point of calibration. It is important that ready means for variation of friction compensation should be provided, which can be instantly adjusted to meet the actual conditions surrounding the meter at its point of use. Such means for local adjustment have been provided in numerous

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forms, and are, I venture to think, highly necessary to the ideal electric meter.

Granting that the variations of friction load due to local surroundings can be accurately and quickly compensated by adjustment of the strength of friction compensation, every meter can be made substantially perfect for the point where it is actually to be used, without in any way affecting its total calibration.

It is well established that such friction increases as occur—due to use and surroundings—occur relatively early in the meter's life, the whole tendency being for the friction load to reach a substantially permanent condition after a comparatively brief period of service.

Instead of restoring the meter to its initial condition periodically by cleaning and the like, it becomes possible, where an adjustable compensation is available, to recompensate at the appropriate time for the permanent friction load, and thus restore the meter to a stable condition of equilibrium.

I have now laid before you the considerations which have led me to the conclusion that the two essentials meriting the most careful study in meter design are:

First, the expenditure of the maximum permissible amount of work in the foucault disk; and

Second, the provision of the best means for instantly compensating for friction variation at the point of use, without affecting total calibration.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 21st, 1901. President Steinmetz in the Chair.

METERING OF ELECTRICAL ENERGY.

BY HARRY P. DAVIS.

The practice is now almost universal in the modern central station to use the integrating wattmeter for measuring and recording and from its reading to compute the charges to be made for supply to the consumers; consequently, it follows that the design of the wattmeter and the conditions under which it is operated, should be such as to omit of no question of its accuracy and permanency. These considerations, with the additional one of small cost of maintenance, are now very generally recognized as essential. As the meter accuracy thus bears so intimate a relation to the revenue return to the station, the meter becomes a factor in station engineering of prime importance, and as a result has received a vast amount of study, both at the hands of the user and of the manufacturer.

It is hoped that the following notes from the writer's experience in this field, although developing nothing particularly new, will outline some of the more important features which should be embodied in the ideal meter; and, for comparison with a commercial type, data and a brief description will be given of a test on a meter with which the writer has been most closely identified, and which is now largely used in practical operation.

While there are many characteristics which a meter must possess, only the more important will be pointed out as being essential to all types of meters. In considering specific features of design, however, it is the intention to cover only the so-called motor types of meters now so generally in use. Experience has

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demonstrated that if a meter is electrically and mechanically well designed with reference to the law and conditions under which it is to operate, and proper care is given to its manufacture, it will be accurate and have the ability to remain in calibration. These features, namely, accuracy and permanency, are fundamental, and the meter which possesses them to a proper degree will surely possess all of the merits which are usually classed as fundamentals.

The meter which is theoretically correct will be influenced only by forces which are directly a product of the quantity which it is to measure. The revolving element will respond in exact proportion to the torque exerted upon it by this quantity and its changes in speed will in no way affect this proprotionality. The retarding force which will act in opposition will be independent of the quantity to be measured, and will increase in proper proportion with the speed of the revolving element.

A meter properly designed to embody these conditions, will measure accurately and be uninfluenced by changes in voltage or temperature, and when used in alternating current circuits will also record true energy under all conditions of inductive or non-inductive load, irrespective of variations in frequency or wave form. While seemingly simple, these conditions can never be completely attained, and many compromises must be made in the development of the commercial type of meter; obviously, however, the nearer they are approached the more accurate will be the meter, and the more extended will be its range of registration.

Commercially the range of accurate registration is most important; for the meter must account for all the conditions and variations of the load, without being delicate and expensive, qualifications requiring accuracy between wide limits, as it must start and record accurately on very light loads, and also be able to operate correctly under considerable overload. Further, the meter to be constant and unvarying in its operation, as it must be to be a practical and commercial success, the mechanical make-up must receive careful consideration, and it is most essential to have:

1st. Simplicity.

2d. Proper design of the rotating element.

3d. Proper design of the enclosing case.

The simple meter will have few parts, with every part easily accessible, and so related to others that the meter may be easily

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taken down and put up without destroying or disturbing in any way the balance or adjustment of the separate parts. Compensating devices are necessary to extend the range and to straighten out the calibration curve. The fewer of these devices used, the better, however, and the amount of compensation needed should be slight, so that their influence may be small.

In the revolving element, we come to the consideration of what is by far the most important feature, in mechanical parts of the meter as a whole. The shaft must be short and stiff, and the entire revolving element must be simple and light in weight; this last consideration is most essential, affecting as it does in a vital manner the portability, life and ability of the meter to remain in calibration. When made sufficiently light all possibility is eliminated of injury to the jewel support, and the meter will respond instantly to sudden changes or fluctuation of load. Artificial, complicated and delicate devices for obviating injury to jewels or to act as substitutes for them, should be unnecessary if careful attention is given to these considerations in the design and proportions of the revolving element, for unless very well designed, such devices are liable in the long run to be troublesome.

No practicable form of bearing for a commercial meter in the writer's opinion, will have less friction or be more durable than a jewelled step bearing, provided the weight of the revolving element is not greater than a few grammes, with a speed of rotation as slow as is consistent with accurate registration on light loads. It is important also that meters used in alternating current circuits should be so proportioned that there will be no vibration effects, as they cause wear on the revolving element and its bearings, and in commercial use will attract the customer's attention and cause him dissatisfaction, owing to his belief that the noise evidences operation of the meter at times of no load.

Another and most potent factor having influence on the ability of a meter to remain in calibration is one entirely independent of the working parts of the meter proper, and yet requires as careful designing and proportioning in every way; and that is the enclosing case. This is a part of the meter, however, which, until recently, has been sadly neglected, and has resulted in being the cause of more trouble, in practical operation, than all other causes put together. A meter with a thin sheet metal

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cover cannot be made tight, and soon becomes filled with dust and dirt, spiders, cockroaches, flies, etc. A meter is a precision instrument, and those with experience know the effect of a small amount of dirt on accuracy. The well designed case should be of light but substantial cast material, with the cover designed to make a tight joint with the base portion, and so arranged that it can be hermetically sealed, thereby effectually enclosing the interior of the meter. This requires the mechanism of the meter to be in a separate compartment from the terminals, but results to its advantage, as it enables connections to the circuit to be made, without any possibility of injury to the meter. A meter case made in this way will be dust, insect and moisture proof, and at the same time one which cannot be tampered with. These details, while purely mechanical, cannot be too highly emphasized, as they have so important a bearing on the permanency of the calibration curve. These are also points of design not always apparent and recognized for their full value on first examination and a test of a meter, but whose worth can only be established by the time test of actual operation.

The fact has been briefly noted of the qualifications and the wide limits which the calibration curve of the meter must possess to enable it to be elastic enough to meet the exacting requirements of the modern central station. As these requirements have been the keynote in meter development in the last five or six years, and as a proper appreciation of their value is most important in central station engineering, the matter is again referred to, and will be explained more in detail. The gradual increase in residential lighting to its present large proportion of every station's load presented new problems, many being of the greatest commercial importance. Residential lighting, especially in the districts far removed from the station, involves a high installation cost, with a corresponding low return per lamp installed. In these installations the maximum demand rarely exceeds one-third of the lamps connected, while one or two lamps may be burned for a considerable period. In central stations supplying such loads it is not an exaggeration to state that ten to fifteen per cent. of the 24 hour output is used in supplying individual installations, burning only one or two lamps for any great length of time, yet each having a total of 20 or 30 lamps installed. These are loads which, when measured by a meter

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unsuited to their character, can be supplied indefinitely, with but slight return to the station, owing to the inability of the meter to register the small load with any degree of accuracy. This condition was becoming apparent as early as 1896, and much pressure was brought to bear on the manufacturers to produce a meter suitable to meet these requirements, namely, a meter with an unusually long range. Most of the difficulty was inability to start, and inaccurate registration on light loads, and the meters having no overload capacity it was necessary to install one having a normal capacity much greater than the average load to be measured. A meter was needed which would record accurately at least within two per cent. whether one lamp or the entire number installed, were burning, or, as previously stated, long range of registration in the meter was necessary. The fact was also apparent from the nature of the loads that if a meter could be designed which could stand a considerable overload for short periods, and register the same within fair accuracy, it would allow of a meter being installed of much smaller rated capacity than that of the installation, making it practicable to use a meter whose capacity would correspond to the average, instead of the maximum load of the installation. The use of a meter of small capacity would also have the advantage of giving a better registration for light loads, and proper selection of the size of meter to be installed would ensure accurate registration of the smallest load which would be placed on the circuit. Such were the conditions to be met, and meter design in the last few years has shown surprising development in this direction. In the central station, if careful attention is given to the fitting of the meter to the load to be measured with special reference to installations of this nature, where the necessity is so great for a meter which will start and record accurately at light load, and at the same time have ability to take care of an occasional overload, it is safe to say that a very considerable increase of revenue will result. This amount will be sufficient, in many instances where improper meters are in use, to pay in a very short time for the entire cost of the new meters and their installation, and to increase the revenue on the entire system by a very respectable percentage.

In a large central station, whose customers include many large apartment houses, and where particular attention has been paid to proper metering of this class of customers, it is customary,

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when a whole apartment house is to measure on one meter (the entire installation will average 300 lamps, with about 12 lamps per apartment) to install a meter having a capacity of about 25 per cent. of the total number of lamps wired, and if each apartment is to be metered separately, a meter is used having 50 per cent. of the lights wired.

It is readily seen, that the use of meters of such small rated capacity, to that required for the total number of lamps installed, results in very accurate return of the light loads, which are usual for this class of installations. To perform such service, it requires great overload capability for the meter to be able to carry current now and then so greatly in excess of the normal, without a large drop and heating effect in the series coil. It is, therefore, important that this coil be of very low resistance, thus requiring it to be small, with few convolutions of wire. This will result in a small magnetizing force, and it is necessary in order to obtain the requisite turning moment on the revolving part, that the magnetic organization of the meter be nearly a closed iron circuit. It should be also noted in this connection that a series coil so designed will have a loss at full load, so slight as to be negligible, which is a valuable feature, as a large loss in the series coil of a meter causes a drop in voltage which will affect the regulation of the circuit, a loss, too, which occurs when the load on the system is the greatest. The use of a closed magnetic circuit has another important and useful bearing on the accuracy of the meter; as it makes it proof from the effects of external stray fields, concentrating as it does its own magnetizing field.

To show to what extent these conditions have been realized in commercial form, a single phase integrating wattmeter of Westinghouse manufacture was selected at random from stock for test. This wattmeter is of the induction type, in which the magnetic field produced by the windings induce secondary currents in an aluminium disk, causing it to rotate, in the same manner as the armature of an induction motor. The design of this meter has been carefully worked out, to give the best all around result in actual use. The coils are wound on iron cores, with very nearly closed magnetic circuits, thus greatly reducing the magnetizing forces necessary. This is particularly noticeable in the series coil which in an 80-ampere meter consists of but one turn of wire having a length of about three inches. Meters

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of other capacities have a proportionate number of turns. As so small a magnetizing force is required, it is evident that the induction drop will be small, and as there are so few turns of wire, it can be made with a very low resistance, conditions which are very necessary to enable the meter to stand a heavy overload. The aluminium disk with its shaft is very light, weighing but 15 grammes.

Figure 1 is the calibration curve of the meter mentioned above. This shows that from 1/50 of full load, to 1½ times full load this meter is correct within 1½ per cent. and at twice full load it is still within 3 per cent. The small loss in series coil of this meter can best be appreciated when it is stated that during this test it carried without injury to itself for a considerable period a load of six times the rated full load capacity of the meter, representing a heating effect in the series circuit of 36 times that occurring at its normal rating.

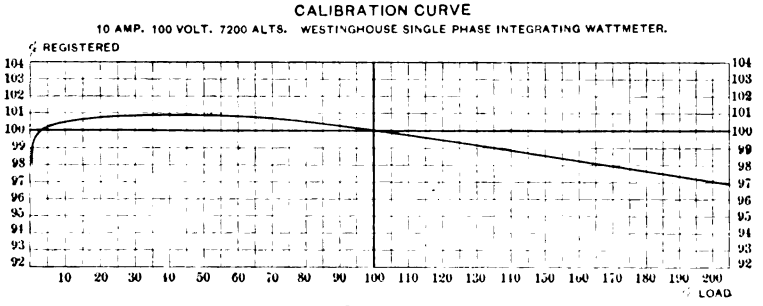

Fig. 1.

The writer would not consider this paper complete without a brief reference to the metering of polyphase currents, as this subject has now become a question of importance, owing to the rapid increase in the use of polyphase apparatus. The type of meter to use, the way to read the counters, the manner of connecting, and the limitations of the various connections, are not very generally understood, causing a great many difficulties and questions to be constantly arising. The energy delivered to a polyphase circuit can be measured by the use of one single-phase wattmeter, two single-phase wattmeters, or one polyphase wattmeter. A two-phase circuit may be treated as two similar

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single-phase circuits, and with a single-phase meter connected in one of them, its reading will indicate one-half the total energy supplied in the two circuits. It is obvious that to have the readings of any value for both circuits, it is absolutely necessary that the loads on the two phases be balanced; that is, of the same amount.

The use of a single-phase meter on a three-phase circuit is more complicated, as it is necessary to make special connections to obtain practicable readings, the connections being such as to make the meter show one-half of the total energy in the whole circuit. In order to have the reading, however, of total energy correct, the loads on the phases must be balanced.

With two single-phase meters, a two-phase circuit can be metered correctly whether balanced or unbalanced, the sum of the readings of the two meters in all cases giving the total energy in the circuit.

In a three-phase circuit the same is true, except that the meters will not give similar readings when the power factor of the circuit is less than unity, and with the power factor lower than 0.5 one of the meters will reverse and run backwards. It is necessary, therefore, in order to arrive at the total energy, to use the algebraic sum of the readings of the two meters. This difficulty can be overcome and the meter made to read equal amounts, with varying power factors and balanced loads, by the use of specially connected meters, which will give an apparent transformation of the three-phase circuit to a two-phase circuit before it is measured. The use of two single-phase meters is undesirable, owing to the necessity of reading two meters and adding the reading, to arrive at the total energy, and it is further aggravated by the negative values shown on one meter on three-phase circuits of low power factor, and if connected to obviate the trouble, the connections are difficult and complicated to be made.

The use of a polyphase meter overcomes all of these difficulties, as it can be connected either to a two or three-phase circuit, the connections being straightforward, and what is most important, its reading will be on a single dial, and will show the total energy irrespective of unbalancing of the loads or changes in power factor. It can be seen, therefore, that the whole question of using single-phase meters on polyphase circuits depends en-

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tirely on the balancing of the loads on the several phases, and the power factor of the circuit. In view of the uncertainty of the polyphase circuits in this respect, the exclusive use of polyphase meters is to be recommended, ensuring, as they do, accurate registration without regard to these irregularities.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 21st, 1901, President Steinmetz in the Chair.

POWER FACTOR INDICATORS.

BY WILLIAM HAND BROWNE, JR.

The introduction of induction motors in factories brings with it a power factor considerably less than unity. Since this requires a larger current for a given power delivered, the total available output of the generating plant is less, and the efficiency of the system is lower than if the load were non-inductive. Further, the wattless component of the current causes increased armature reactions, and consequently seriously affects the regulation of the system.

It therefore may be thought desirable to balance wholly or in part the wattless component of current, due to the induction motors, by the use of synchronous motors or converters, and it then becomes necessary to have some means of knowing when this has been accomplished.

Methods of Determining Balance.—One method of judging the conditions of the system, which is used to some extent, is to place an ammeter in the line carrying the current for both induction and synchronous motors. Then to secure a balance, the excitation of the synchronous motor is changed until the line current is a minimum. This method, while simple, is exceedingly crude, and becomes entirely unreliable when the synchronous motor is fairly well loaded. As the power factor of the system approaches unity under these conditions, a comparatively large change in the excitation of the synchronous motor produces little or no apparent change in the ammeter reading. This is because the characteristic v curve of the synchronous motor, *i. e.*, arma-

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ture current on a field current base, is quite flat for large loads. The wattless component of current, however, changes very rapidly as will be shown later. The same criticism applies to the use of an indicating wattmeter for securing balance. Here the excitation of the synchronous motor is changed until the volt amperes as found from the ammeter and voltmeter readings are equal to the true watts as indicated by the wattmeter.

To show that both of these methods are unreliable, suppose a small error has been made in reading the ammeter or wattmeter, due to carelessness or to instrumental errors. Fig. 1 illustrates the effect of this error on the wattless component of current, or what

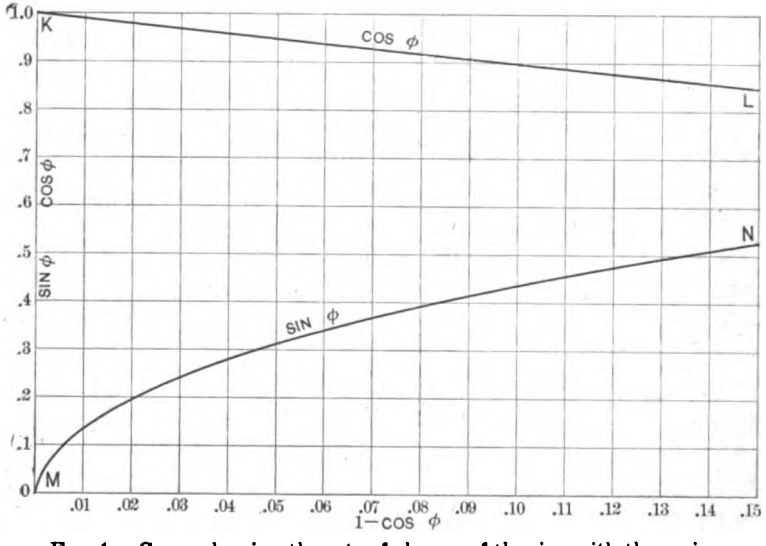

FIG. 1.—Curve showing the rate of change of the sine with the cosine.

is the same thing on sin φ, the inductance factor; K L represents the power factor for different percentage differences between the true and apparent watts, M N is the corresponding inductance factor curve. For an error of 1 per cent. the inductance factor is .14. For an error of 2 per cent. the wattless component of current is nearly 20 per cent. of the total current. That is to say, when the attendant thinks he has secured a balance, the wattless current may still be a very considerable fraction of the whole, and seriously affect the regulation of the generator.

Behavior of a Synchronous Motor.—Fig. 2 shows how a synchronous motor will behave under these conditions. Here a con-

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stant applied voltage and a constant true watts input have been assumed, with a variable inductance factor. That is to say, $EI\cos\varphi$ is constant, at 5 kilowatts, represented by the horizontal line FA. (Fig. 2).

The base taken here is $EI\sin^2\varphi$. The curve B C is $\cos\varphi$ for different values of $EI\sin\varphi$. The curve O D shows the corresponding values of $\sin\varphi$; F G is the armature current. These curves show

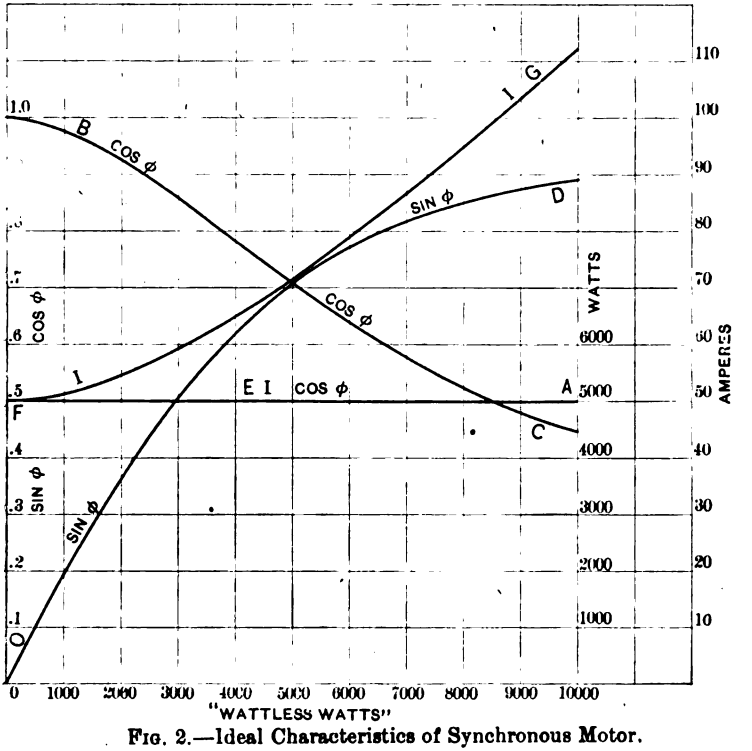

FIG. 2.—Ideal Characteristics of Synchronous Motor.

that as we approach unity power factor $\cos\varphi$ changes slowly and the total current changes slowly, but $\sin\varphi$ (and hence $I\sin\varphi$) changes very rapidly.

The need of an instrument which will indicate accurately the condition of the system as regards balance being evident, it becomes worth while examining the methods and instruments available for such determinations, as well as the quantities to be measured. The phase difference of two waves is usually defined as the displacement in degrees between the points where they

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pass, in the same direction, through zero or their maximum values. In alternating current theory, where the two waves are assumed sinusoids and one is the E.M.F. and the other the current, the cosine of the phase angle is called the power factor. It is equal to the ratio of true watts to volt amperes. In practice while we may not have sinusoids, this ratio is still called the power factor and may be considered as the cosine of the phase angle of the equivalent sinusoids.

As pointed out above, measurements for determining the phase angle are unsatisfactory when involving the cosine, if the cosine approaches unity. We must measure either the phase angle directly or indirectly, or what in most cases would be equally satisfactory. the wattless volt amperes; that quantity Mr. Steinmetz has called the "wattless power."

Unfortunately few of the methods suggested for measuring these quantities are more than laboratory methods, and the instruments used are unsuitable for practical work. The split dynamometer of Blakesley, the three voltmeter method of Fleming, and the three ammeter method of Sumpner are too familiar to need description here, and are hardly applicable under the usual operating conditions. There are, however, two or three instruments which give satisfactory service under proper conditions.

Classification.—Power factor indicators may be divided into four classes:

1. Phase meters, by which the phase angle is determined directly.

2. Power factor meters, measuring a function of the phase angle.

3. Wattless power meters, measuring $E I \sin \varphi$.

4. Wattless current meters, measuring $I \sin \varphi$.

In the first class we may include, in addition to types to be described below, all forms of oscillographs and curve tracers.

In the second class we may include all instruments measuring $\sin \varphi$ and $\tan \varphi$ as well as $\cos \varphi$.

These classes may be further subdivided, according to the means employed to obtain an indication, into four types:

(*a.*) Electromagnetic, using the force of attraction of electromagnets.

(*b.*) Electro-dynamic, utilizing the reaction between coils carrying currents.

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(*c*.) Induction, a rotating magnetic field is set up and used to deflect a disk.

(*d*) Electrolytic, depending upon electrolysis to secure a record.

Phase Meters.—The various types of oscillographs and curve tracers are too well known to need description. In general they are laboratory instruments and not applicable to commercial working.

Tuma's Phase Meter[1] (1*b*).—Let the pair of coils A B (Fig. 3) carry the current whose phase angle, referred to the E. M. F. is desired.

Within the space between the two, suspended freely, is the movable system C D, consisting of two independent windings connected together mechanically at right angles. Let α be the angle

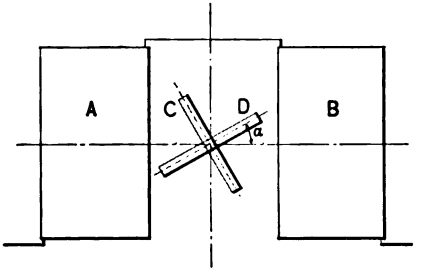

FIG. 3.

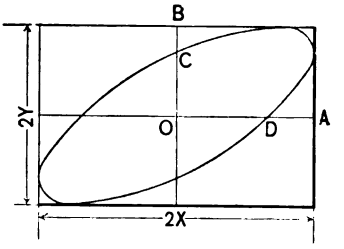

FIG. 4.

which D makes with the axis of A B.

When a current $i_1 = I_1 \sin(\omega t - \varphi)$ passes through A B; this sets up an alternating flux in the space between them equal to

$$N = N_0 \sin(\omega t - \varphi)$$

N_0 being the maximum value of the flux and $\omega\, 2\pi$ times the frequency. Through D pass a current in phase with the E. M. F. This will be

$$i_2 = I_2 \sin \omega t$$

1. J. Tuma in *Sitzungsberichte der K. Preussischen Akademie der Wissenschaften*, vol. 106, p. 521, 1897. M. Brieger in *Bulletin de l' Association des Ingenieurs Électriciens*, vol. 11, p. 79, 1899. Aug. J. Bowie, Jr., in *Electrical World and Engineer*, vol. 36, p. 644, 1900. (Mr. Bowie works out the general condition and shows the application to two and three-phase circuits.) H. Armangat in *L'Éclairage Electrique*, vol. 25, p. 339. (Hartmann and Braun instrument.)

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And through C pass a current in quadrature with this

$$i_3 = I_3 \sin\left(\omega t - \frac{\pi}{2}\right)$$

The torque set up between A B and D will be

$$T_1 = N i_2 \sin \alpha$$

Between A B and C

$$T_2 = N i_3 \cos \alpha$$

Substituting for N, i_2 and i_3, the values given above, the effective values are

$$T_1 = \frac{N_0 I_2}{2} \sin \alpha \cos \varphi$$

$$T_2 = \frac{N_0 I_2}{2} \cos \alpha \sin \varphi$$

Since the coil is free to turn, the angle α will be such that $T_1 = T_2$, then

$$\frac{N_0 I_2}{2} \sin \alpha \cos \varphi = \frac{N_0 I_2}{2} \cos \alpha \sin \varphi$$

$$\tan \alpha :: \tan \varphi$$

The angle α is the phase angle.

Induction Phase Meters (1*c*).—If we pass through two coils, concentric but set at an angle with each other, currents which set up equal fluxes differing, however, in phase, a rotating magnetic field of elliptical form will in general be created. If the two coils are inclined at an angle which is the supplement of the phase angle, the resulting field will have a constant value. An armature suitably placed in such a field will cause a ray of light reflected from an attached mirror to travel in a circle. In applying this method it is necessary to have the fluxes of equal value and to change the angle between the coils until the ellipse becomes a circle when the phase angle is read off directly. The instruments of Angelmeyer[1], Korda[1], Hess[1], Rossi[2] and one of Arno[3], make use of this principle.

1. (*a*) "Mesure des Differences de Phase." F. Fontaine in *Bulletin de l' Association des Ingenieurs Electriciens*, Nov. 1899.

2. *L'Eclairage Electrique*, vol. 15, pp. 133, 322, 355, 1898.

3. *Ibid*, vol. 21, p. 225, 1899.

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Electrolytic Phase Indicator (1*d*.)—A very simple device, due to Janet[1], consists of a metallic drum upon which rest two styli of iron. One of these is connected so as to have a difference of potential between it and the drum which is in phase with the current, the other one which is in phase with the E. M. F. On the drum is stretched a sheet of paper which has been soaked in potassium ferrocyanide and ammonium acetate.

When the difference of potential between either stylus and the drum reaches a certain positive value, electrolysis begins and the paper under that stylus turns blue. Now if the drum be turned, each stylus traces a broken blue line on the paper, each blue mark representing part of a positive half wave. The angular distance from the center of one of these short lines and that of the corresponding mark made by the other stylus, expressed in electrical degrees, is the phase angle. This is true only when the two waves have the same form.

Power Factor Meters (2).—Two harmonic motions acting at right angles and having the same frequency and amplitude but a difference in phase of 90°, will produce, if acting at the same time, a uniform circular motion. If the amplitudes are not the same, the result is an ellipse, the major and minor axes of which are the respective paths of the two harmonic motions.

If the phase difference is not 90° the two axes of the resulting ellipse do not coincide in direction with the two harmonic motions.

Puluy's Power Factor Meter (2*a*).—The principle just described has been made use of by Puluy. Two electro-magnets, through the winding of each of which, one of the currents, the phase difference of which is desired, is passed, act upon two armatures causing them to vibrate in planes normal to each other. A ray of light falling upon a mirror attached to one of these and reflected to a second mirror on the other, and thence to a screen, will describe an ellipse, the shape and position of which is determined by the values of the two currents and the phase difference.

Let X be the amplitude of one vibration and Y that of the other. It is evident that a rectangle, the sides of which are respectively $2X$ and $2Y$, can be circumscribed about this ellipse, Fig. 4. Now when either one of the magnets is acting alone, a

1. See reference (*a*) above.

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straight line will be described, $2X$ or $2Y$ in length. The intersection of these lines will be the center of the ellipse.

The co-ordinates of any point on the ellipse, referred to these two lines, will be

$$x = X \sin \omega t \tag{1}$$

$$y = Y \sin (\omega t - \varphi) \tag{2}$$

φ being the difference in phase

In equation (1) let $x = 0$, then

$$\omega t = n \pi$$

n being some whole number.

Substituting in (2)

$$y_0 = Y \sin (n \pi - \varphi)$$

$$= \pm Y \sin \varphi = \overline{OC} \text{ (Fig. 4)} \tag{3}$$

Again let $y = 0$ in (2), then

$$\omega t - \varphi = n \pi$$

$$x_0 = X \sin (n \pi + \varphi)$$

$$= \pm X \sin \varphi = \overline{OD} \text{ (Fig. 4)} \tag{4}$$

From (3) and (4) it follows that

$$\sin \varphi = \frac{OC}{OB} = \frac{OD}{OA}$$

Morland's Power Factor Meter.—In an apparatus described by Mr. Morland[1], the two conductors carrying the two currents pass between the poles of a permanent magnet. Each of these causes a small mirror to vibrate, producing the result just described.

Claude's Power Factor Meter.—Claude[2] places the two electro-magnets in direct opposition and causes them to actuate the same armature. Let the maximum flux set up by each coil be N. The ray of light reflected from the mirror will under the influence of the flux N oscillate along a path in length KN, K being a constant. If both coils were acting and if the currents were in phase, the length of this path would be $2KN$.

1. Apparatus for illustrating change of phase, S. I. Moreland, *Electrical Engineer*, Vol. 26, p. 237, Sept. 8, 1898.

2. See reference (*a*) above.

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Call this d_1. At any instant the flux due to one coil will be

$$N_1 = N \sin \omega t \tag{1}$$

That due to the other will be

$$N_2 = N \sin (\omega t - \varphi) \tag{2}$$

Writing (1)

$$N_1 = N \sin \left[\left(\omega t - \frac{\varphi}{2}\right) + \frac{\varphi}{2}\right]$$

and (2)

$$N_2 = N \sin \left[\left(\omega t - \frac{\varphi}{2}\right) - \frac{\varphi}{2}\right]$$

and taking the sum we have

$$N_1 + N_2 = 2\, N \sin \left(\omega t - \frac{\varphi}{2}\right) \cos \frac{\varphi}{2}$$

and the path to the ray is

$$2\, N\, K \cos \frac{\varphi}{2}.$$

Call this d_2.

Then it follows that

$$\frac{d_2}{d_1} = \cos \frac{\varphi}{2}.$$

It is evident from what has been said above that this method will not be accurate when φ approaches zero.

Rayleigh's Power Factor Meter (2*a*).—Lord Rayleigh's apparatus[1] for measuring phase angles is somewhat similar to the above. The movable loop is replaced by a soft iron needle and the two coils are placed on opposite sides of this. The equation then becomes

$$d_1 + d_2 + 2 \sqrt{d_1\, d_2 \cos \varphi} = d_3$$

The deflections are measured as in a reflecting galvanometer. Mr. Edwin Place[2] gives the results of a great number of experiments made with an instrument of this type. He shows that the angle found in this way is that between the equivalent sine waves. The cosine of this angle, however, is not given by the ratio of true watts to volt amperes, the true power factor.

Tuma describes an instrument similar to the above but with

1. *Philosophical Magazine*, May, 1897.
2. *Electrical World and Engineer*, May 13, 1899, p. 614.
3. *Sitzungsberichte der K. Preussischen Akademie der Wissenschaften* (Berlin) vol. 106, p. 442, 1897.

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the coils at right angles. One of these lies in the magnetic meridian.

He shows that, with specially wound coils, if φ is the phase angle and ψ the angle between the needle and that coil which lies in the magnetic meridian, then

$$\cos \varphi = \tan 2 \psi.$$

Dynamometer Types.—A Siemens electro-dynamometer[1] having two fixed coils may be used for phase angle measurements if the movable system be replaced by a coil closed upon itself and suspended in the plane of the other two.

1. If a current $i_1 = I_1 \sin \omega t$ be passed through one coil, it will set up an E. M. F. in the movable loop

$$e_1 = - M \omega I_1 \cos \omega t.$$

2. When the current $i_2 = I_2 \sin (\omega t - \varphi)$ passes through the second coil it will set up in the movable coil an E. M. F.

$$e_2 = - M \omega I_2 \cos (\omega t - \varphi)$$

M is the mutual inductance and is assumed the same in each case.

3. If the two currents are flowing at the same time, we have in the movable coil

$$e_1 + e_2 = - M \omega [I_1 \cos \omega t + I_2 \cos (\omega - \varphi)]$$

Denoting the angles of torsion necessary to keep the movable coil in its zero position in the three cases by d_1, d_2 and d_3, respectively, and by t the constant of the instrument by K, we have

$$K d_1 = M^2 \omega^2 I^2_{1\,\text{eff}}$$

$$K d_2 = M^2 \omega^2 I^2_{2\,\text{eff}}.$$

$$K d_2 = M^2 \omega^2 (I^2_{1\,\text{eff}} + I^2_{2\,\text{eff.}} - 2 I_1 I_{2\,\text{eff.}} \cos \varphi$$

Hence

$$d_1 + d_2 - 2 \sqrt{d_1 d_2} \cos \varphi = d_3$$

and the phase angle is deduced from this relation.

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1. See reference (*a*) above.

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Arno's "Tangent Phase Meter" (2*b*).—A second power meter of Arno's[1] consists of a Siemens electro-dynamometer with an additional pair of coils closed upon themselves and fastened together at right angles. The pair as a whole is suspended within the two other coils and may be held in any position by a torsion spring. In Fig. 5 let A and B be the two coils of the dynamometer and C and D the pair of short-circuited loops.

Passing the two currents through A and B respectively, the instrument becomes a wattmeter and we have

$$I_1 I_2 \cos \varphi = k_1 d_1 \qquad (1)$$

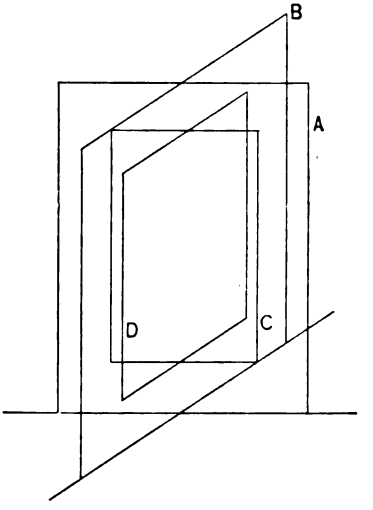

FIG. 5.

where d_1 is the angle of torsion required to keep the movable coil in position. k_1 is the constant for this system.

Now fix B and pass the current I_1 through A, this will set up in C an E. M. F.

$$e_1 = - M I_1 \omega \cos \omega t = M I_1 \omega \sin \left(\omega t - \frac{\pi}{2}\right)$$

This will cause in C a current

$$i_1 = \frac{M_1}{r_1} I_1 \omega \sin \left(\omega t - \frac{\pi}{2}\right)$$

1. *L'Eclairage Electrique*, vol. 12, p. 520; vol. 21, p. 226; vol. 25, p. 484; also reference (*a*) above.

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The inductance of the loop is assumed negligible; r_1 is the resistance.

This current being in quadrature with that in A will set up no torque.

The current in A will have no inductive effect upon the loop D since they are kept at right angles.

If at the same instant a current I_2 is passed through B, we will have at this instant in B

$$i_2 = I_2 \sin (\omega t - \varphi)$$

$$e_2 = M I_2 \omega \sin (\omega t - \frac{\pi}{2} - \varphi)$$

and a current

$$i'_2 = \frac{M}{r} I_2 \omega \sin (\omega t - \frac{\pi}{2} - \varphi)$$

This assumes the same mutual inductance for each pair of coils and the same resistance for the two loops C and D.

This current will react with that in A and set up a torque proportional to their product

$$\frac{M I_1 I_2}{r} \omega \sin \omega t \sin (\omega t - \frac{\pi}{2} - \varphi)$$

The effective value of this torque is

$$\frac{M I_1 I_2}{2 r} \omega \cos \left(\varphi + \frac{\pi}{2}\right) = \frac{M I_1 I_2}{2 r} \omega \sin \varphi$$

It is evident that the couple existing between B and C will have the same value but have an opposite sign, since the current in C being in quadrature with that in A will be less than 90° behind B, while that in D will be more than 90° behind A.

The resulting torque of the system is proportional to $I_1 I_2 \sin \varphi$ and may be written

$$I_1 I_2 \sin = k_2 d_2 \qquad (2)$$

where k_2 is a constant and d_2 the angle of torsion.

Dividing (2) by (1) we have

$$\frac{k_1 d_1}{k_2 d_2} = k \frac{d_1}{d_2} = \tan \varphi$$

giving the phase angle in terms of its tangent.

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Breitfield's Method (2*b*).—Mr. C. Breitfield[1] has suggested an application of an ordinary wattmeter for measuring the power factor of a three-phase system. The current coil is placed in one line and one end of the pressure coil also connected to this line. The other end is first connected to the second line and then to the third. In the first case we have the deflection

$$d_1 = E\,I \cos(\varphi - 30°)$$

In the second

$$d_2 = E\,I \cos(\varphi + 30°)$$

From these equations we have

$$d_1 - d_2 = E\,I \sin\varphi \sin 30°$$

$$d_1 + d_2 = E\,I \cos\varphi \cos 30°$$

Hence

$$\tan\varphi = \sqrt{3}\left[\frac{d_1 - d_2}{d_1 + d_2}\right]$$

General Electric Company's Instrument (2*b*).—The well-known fact that the ratio of the readings of the two wattmeters used to measure the power of a three-phase system changes with the power factor and is unity when the power factor is unity, has been made use of by the General Electric Company to indicate the power factor. The instrument[2] is simply two wattmeters of the dynamometer type, the movable coils of which are attached to the same spindle. The instrument deflects to the right or left according as the current lags or leads, and stands at zero when the system is balanced and the power factor unity.

Ferraris' Power Factor Meter (2*c*.).—Ferraris[3] combines two harmonic fields, producing a rotating field of elliptical form. Within this field is suspended a short-circuited coil which can be held in any position, by a torsion spring, as is the movable coil of a Siemens dynamometer. The force required and therefore the angle through which the spring must be turned, to hold the coil in any position is proportional to the square of the intensity of the flux in that direction. Points can thus be determined and

1. *Electrotechnische Zeitschrift*, vol. 20, p. 120, 1899.
2. *Electrical World and Engineer*, vol. 37, p. 688, April 27, 1901.
3. See reference (*a*) above.

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the ellipse plotted and the sine of the phase angle deduced as above. (See Puluy's Method, page 481.)

Power Factor Indicators (*3*).—In the methods described above, the object sought was the determination of the phase angle. But few of these are applicable under the usual operating conditions. We might mention as useful forms, those of Tuma and the General Electric Co. In most cases, however, we are more concerned with the magnitude of the wattless component of current than with the power factor. We care less about the decrease in the total output than about the poor regulation caused by inductive loads. Instruments which will indicate the wattless current, or rather the wattless volt amperes are easily made in commercial form.

"*Wattless Wattmeters.*" *Dynamometer Type* (*3b*).—A Siemens dynamometer becomes a wattmeter indicating $EI \cos \varphi$ when the current is passed through one coil and a current proportional to and in phase with the E. M. F. through the other.

If the current in the pressure coil be in quadrature with the E. M. F. the instrument indicates $EI \sin \varphi$, the wattless volt amperes.

This is easily done with a two-phase system. With a single-phase system it is necessary to place a proper condenser or inductive reactance in series with the pressure coil.

"*Wattless Wattmeters.*" *Induction Type* (*3c*). *Dobrowolski's Power Factor Indicator*[1].—In a fully compensated induction meter the shunt flux is in quadrature with the series flux, the result of the two being a rotating or shifting field. If the shunt flux be brought into phase with the series flux an alternating field only will be set up as long as the current and E. M. F. are in phase. If, however, the current lags, the field will rotate in one direction. If it leads, the field will rotate in the opposite direction. The torque developed on a disk placed in this field is, in either case proportional to $EI \sin \varphi$, the wattless volt amperes. This is the principle of Dobrowolski's apparatus.

The movable disk is held in its zero position by a spring when the wattless volt amperes are zero, but deflects one way or the other, when the current is out of phase, an amount proportional to $EI \sin \varphi$.

Any induction wattmeter can be used in this way provided the flux through the pressure coil be brought into phase with the E. M. F.

1. U. S. Patent No. 549,449, 1895.

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Wattless Current Meters (*4*).—The Allegemeine Electricitäts Gesellschaft make an instrument[1] which indicates the wattless current. This is really an induction wattmeter having the shunt flux in phase with the E. M. F. and indicates therefore only when there is a phase difference. As an instrument of this type indicates $EI \sin \varphi$, it is presumed that this meter is graduated to read

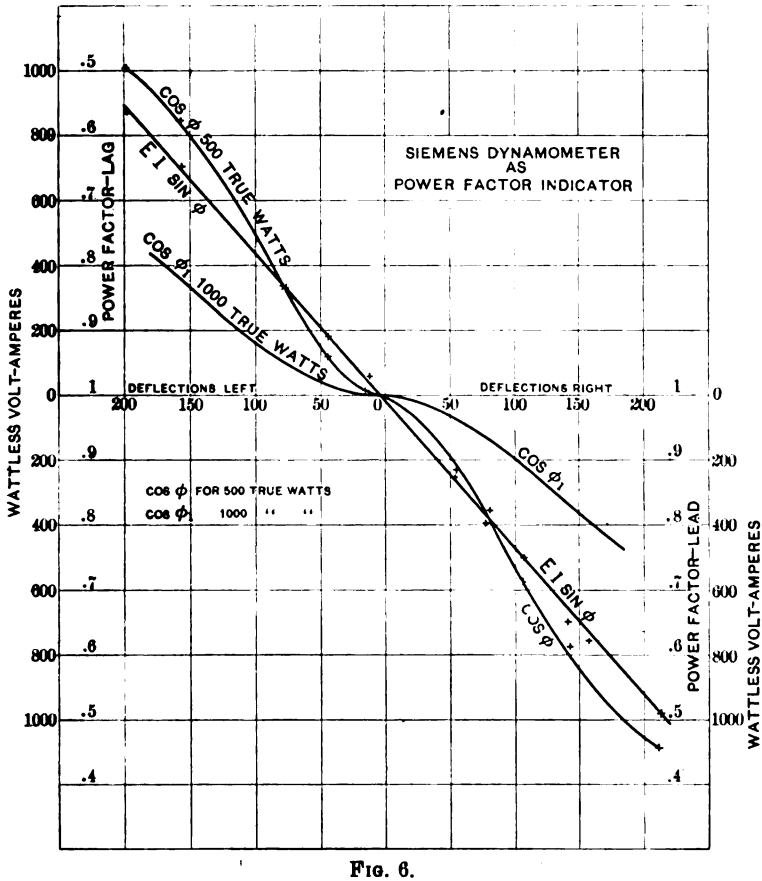

FIG. 6.

$I \sin \varphi$ at normal voltage, and should properly come under "wattless wattmeters" (*3c.*)

BEHAVIOR OF POWER FACTOR INDICATORS.

The Siemens Electro-dynamometer.=The following set of curves (Fig. 6) were taken with a Siemens dynamometer, the

1. *L'Eclairage Electrique*, vol. 35, p. 339.

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movable coil of which was in series with a capacity of 3.5 microfarads. The values of $\cos\varphi$, $\sin\varphi$ and $EI\sin\varphi$ plotted have been computed from ammeter, voltmeter and wattmeter readings given in Table I.

$EI\sin\varphi$ is a straight line and is plotted above and below the axis to indicate lagging and leading currents respectively. The base is the deflection in degrees. These curves were taken for a constant power delivered, of 500 true watts. The displacement of current was obtained by means of a phasing transformer. For comparison between $EI\sin\varphi$ and $\cos\varphi$ the axis of abscissæ is taken as unity for the latter, and the decreasing values plotted above and below this.

TABLE. I.

Siemens Dynamometer as Power Factor Indicator.

Amp. I	Volts E	Watts $EI\cos\varphi$	Deflection.	Direction.	Phase	Apparent watts EI	Power factors $\cos\phi$	Inductance factors $\sin\phi$	$EI\sin\varphi$
10.15	108	500	213	Right	Lead	1096	.456	.889	975
8.4	108	500	158	"	"	907	.552	.834	755
7.58	107.9	600	141	"	"	818	.611	.791	647
6.51	108	500	106	"	"	703	.711	.703	494
5.63	107.8	500	78	"	"	607	.823	.568	294
5.25	107.8	500	53	"	"	516	.884	.467	241
4.78	105.5	500	13	Left	Lag	504	.992	.126	63
5.05	105.7	500	44	"	"	533	.938	.346	185
5.67	106.1	500	76	"	"	602	.831	.555	334
8.17	106	500	155	"	"	866	.577	.817	707
9.61	105.9	500	197	"	"	1007	.497	.867	873

Note.—Pressure coil in series with 3.5 microfarads capacity.

We notice first that these lines do not pass through the origin. The resistance of the pressure coil is not negligible, as the instrument shows a slight deflection at unity power factor. The curves show very clearly that a slight change in the power factor when near unity caused a comparatively large change in the value of $EI\sin\varphi$.

This fact is very striking when working with the instrument. It may be made to deflect considerably to the right or left without producing any appreciable change in the reading of the Weston wattmeter, the current and voltage remaining constant the while.

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Power factors for larger power delivered, lie below the one just considered and hence are still flatter when approaching unity. One for 1,000 true watts has been plotted from calculated values only. It shows that it would be practically impossible to say from ammeter, voltmeter and wattmeter readings alone, when the current was in phase with the E. M. F. With the power factor indicator, however, there would be no difficulty in getting an almost exact adjustment.

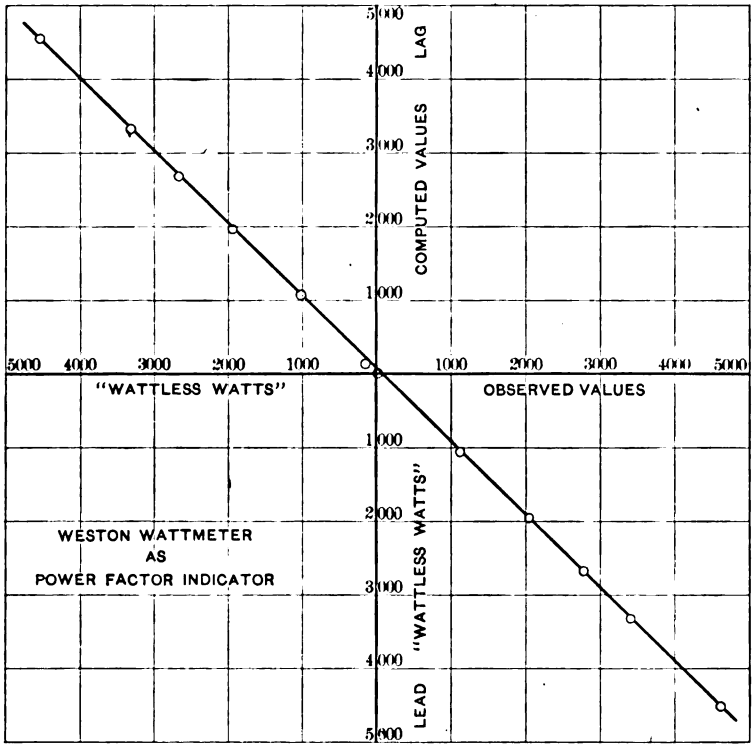

FIG. 7.

Weston Wattmeter as Power Factor Indicator.—In Fig. 7 is given the characteristic of a Weston wattmeter of 150 volts, 50 amperes capacity, used on a two-phase system in the manner described above. The characteristic is a straight line, but does not pass through the origin.

This may be due either to the slight inductance of the pressure coil, or to a slight change in the phase angle between the impressed E. M. F.'s or to both.

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The method of calibrating consisted in connecting the pressure coils of the power factor indicator and wattmeter respectively to the two primary windings of a two-phase induction motor, used as a phasing transformer. The current coils of the meters were in series and connected to the movable secondary. As the secondary is shifted, the load is partially shifted from one phase of the primary winding to the other. This doubtless caused a slight change in the phase angle between the E. M. F.'s at the motor terminals. The motor used was rated at two horse-power. The supply was drawn from two 4 K. W. transformers, both partially loaded in addition with lights.

TABLE II.

Weston Wattmeters as Power Factor Indicator.

True Watts.	Voltage.	Amperes.	Wattless volt amperes observed.	Phase relation.	Volt-amperes.	Power factor.	Inductance factor computed.	Wattless volt-amperes computed.
1970	111.5	44.4	4530	Lag	4950	.398	.917	4540
"	"	34.7	3325	"	3870	.509	.860	3330
"	"	29.8	2690	"	3340	.590	.807	2690
"	"	25.0	1950	"	2790	.706	.708	1975
"	"	20.1	1050	"	2240	.879	.477	1070
"	"	17.7	180	"	1975	.997	.071	140
"	"	17.65	0	—	1970	1.0	.0	0
"	"	20.1	1130	Lead	2240	.879	.477	1070
"	"	25.0	2050	"	2790	.706	.708	1975
"	"	29.8	2785	"	3340	.590	.807	2690
"	"	34.7	3420	"	3870	.509	.860	3330
"	"	44.4	4610	"	4950	.398	.917	4540

The agreement between observed and calculated values of $EI \sin \varphi$ is good. Table II gives observed and computed values for this instrument.

Induction Meters.—In Fig. 8 are shown a set of curves obtained from a Shallenberger integrating wattmeter used as a power factor indicator. The instrument is a 500-volt, 10-ampere meter of the older type (1898). The reactive coil was replaced by a non-inductive resistance of 2,000 ohms. In series with this was a capacity of 3 mf., this being found to balance the inductance of the shunt coil at a frequency of 60 cycles. In this case the instrument was used as a recording meter. The curves plotted are

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EI sin φ, cos φ and φ, all on a revolutions per minute base, for a delivered power of 500 true watts. Table III gives the instrumental readings and computed values for these curves.

Fig. 9 shows the results from the same meter under somewhat different conditions. Here the recording train was removed to lessen the friction, and a light steel spring attached to the spindle of the revolving disk. A pointer attached to the disk

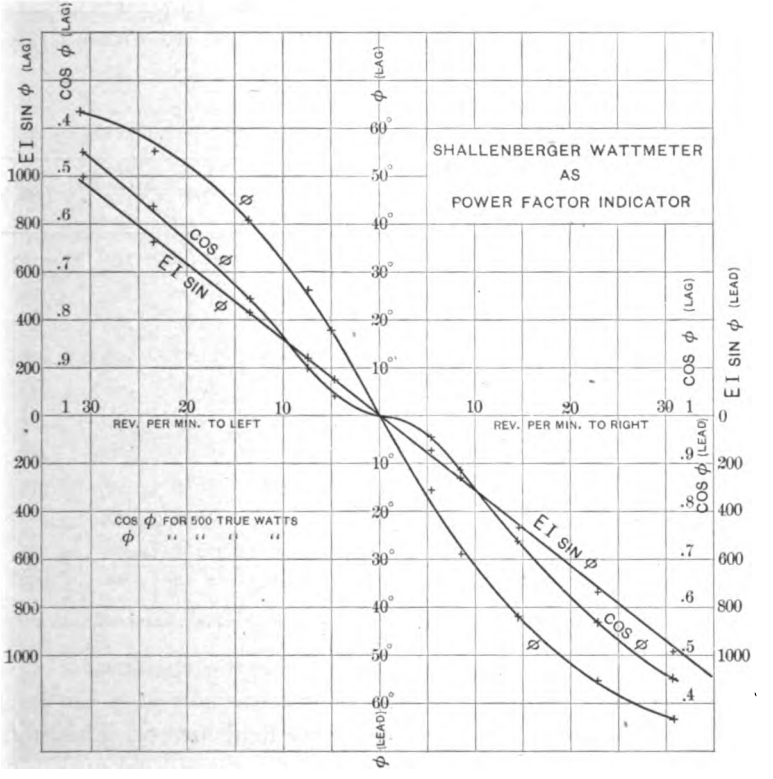

FIG. 8.

passed over a scale marked in degrees. The curves plotted are, as before, EI sin φ, cos φ and φ, for a delivered power of 500 true watts. The base is degrees deflection. It will be noticed that from 20° lag to 20° lead the deflection is almost directly proportional to the phase angle. The flattening of the curve for cos φ is very marked. This instrument was even more sensitive than the dynamometer and besides was dead beat, as the damping

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magnets were left in. Table IV gives the instrumental readings and computed values for these curves.

Application of Power Factor Indicator.—To illustrate the application of a power factor indicator, the Weston wattmeter mentioned above was used to measure the wattless volt amperes taken by a General Electric 7½-kilowatt, 125-volt, four-pole, synchronous converter for different values of field current. The converter was run on a two-phase system at constant input. The supply was drawn from two Westinghouse 7½-kilowatt transformers, O. D. type, fitted with a Hartford regulator. The

TABLE III.

Shallenberger Wattmeter as Power Factor Indicator. 10 amp. 400 volts.

No.	Amp.	Volts.	Watts	r.p.m	Direction.	Phase.	Apparent watts EI	Power factor $\cos\phi$	Phase Angle ϕ	Inductance factor $\sin\phi$	$EI\sin\phi$
1	10.01	111.3	505	30.8	Left	Lagging	1114	.449	63° — 10′	.898	996
2	8	111.5	505	23.4	"	"	891	.567	55—27	.824	734
3	6	111.5	505	13.45	"	"	669	.756	40—53	.655	438
4	5.07	111.0	505	7.45	"	"	563	.898	26—06	.440	248
5	4.78	110.3	505	4.68	"	"	527	.954	17—26	.300	158
6	4.5	111.9	505	0	—	—	504	1.00	0	0	0
7	4.58	114.5	505	5.29	Right	Leading	525	.962	15—50	.273	143
8	5.00	114.3	504	8.7	"	"	572	.881	28—14	.473	270
9	6.09	112.2	505	14.6	"	"	684	.738	42—26	.675	462
10	8.0	111.3	505	22.8	"	"	890	.567	55—28	.824	733
11	10.0	111.2	505	30.6	"	"	1112	.454	63—10	.891	992

Note.—Impedance coil cut out and shunt coil in series with three microfarads and 2,000 ohms.

output was absorbed by a lamp bank and water rheostat.

In Fig. 10, armature, current and wattless volt amperes have been plotted as ordinates, the base being field current. The input was 3½ K. W. per phase. The flatness of the current curve alluded to above is quite noticeable here. The characteristic for wattless volt amperes is plotted above and below the axis of abscissæ to indicate lagging and leading currents respectively.

The instruments were quite steady, a condition indicating but little hunting of the armature, although there were no devices on the machine to prevent this phenomenon. The power factor indicator, although exactly like the wattmeter, was even steadier than the latter. There was no difficulty in setting the indicator to read any desired value by adjusting the field current.

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It was stated[1] at a recent meeting of the National Electric Light Association, during the discussion of a paper on synchronous converters, that it was practically impossible to operate a synchronous motor or converter at unity power factor. The reasons given were hunting of the armature and dissimilar E. M. F. waves of motor and generator. In the above experiment it was found that the power factor indicator could be set at zero and under these conditions the true watts and the volt amperes were equal. This condition would seem to be that of practically unity power factor.

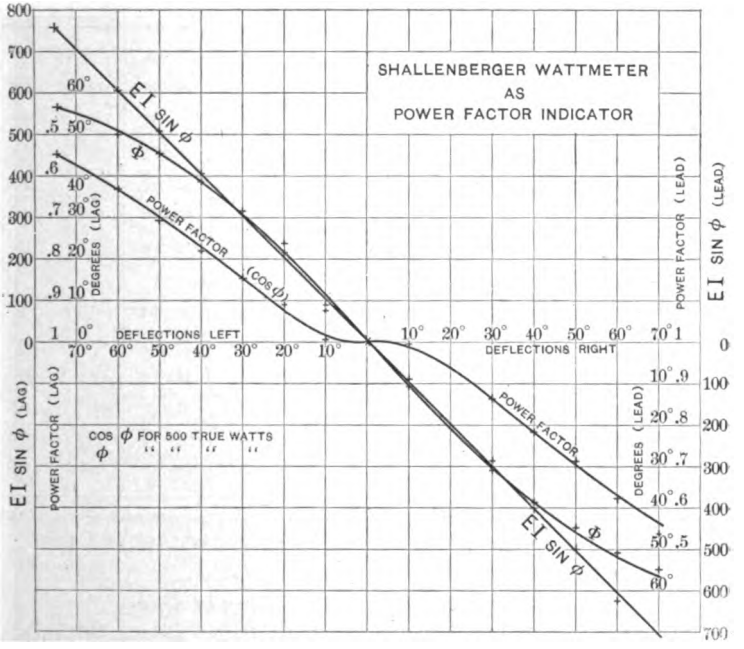

FIG. 9.

A number of power factor curves of synchronous converters have been published recently in which the current passes from lag to lead without the power factor passing through unity. Even if it were impossible to hold the power factor at unity, it must pass through this value as it swings across the line.

In Fig. 11 are plotted, on an excitation base, curves of power factor from wattmeter readings and inductance factor from the

1. *Western Electrician*, Feb. 9, 1901.

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"wattless wattmeter" readings. In addition there have been plotted two curves obtained by assuming these values to be cosines and sines of phase angles and the corresponding values of sines and cosines taken from tables and plotted on the same base. These deduced values do not agree at all with the observed ones. The discrepancy is greater for leading than lagging currents. This discrepancy, as has been pointed out by Mr. Steinmetz[1], is

TABLE IV.

Shallenberger Wattmeter as Power Factor Indicator.

No.	Amperes.	Volts.	True watts.	Degrees deflection.	Direction.	Phase	Apparent watts.	cos ϕ	φ	sin φ	$EI \sin \phi$
1	8.29	110.	500	75°	Left	Lag.	911	.549	56°—42′	.836	761
2	7.27	108.5	500	60	"	"	788	.634	50—39	.773	608
3	6.54	109.	500	50	"	"	712	.702	45—35	.712	507
4	5.85	110.5	500	40	"	"	646	.774	39—17	.633	409
5	5.41	109.2	500	30	"	"	590	.848	32—00	.530	313
6	4.94	109.9	500	20	"	"	543	.921	22—56	.390	212
7	4.57	111.1	500	10	"	"	507	.987	9—04	.158	80
8	4.59	108.4	500	0	—	—	498	1.	0	0	0
9	4.67	109.	500	10	Right	Lead	509	.982	10—53	.189	96
10	5.35	108.	500	30	"	"	578	.865	30—07	.502	290
11	5.87	109.4	500	40	"	"	642	.78	38—44	.626	402
12	6.45	109.7	500	50	"	"	707	.708	45—05	.706	498
13	7.44	107.4	500	60	"	"	799	.626	51—13	.779	623
14	8.16	108.7	500	70	"	"	886	.564	55—40	.826	732

Note.—Impedance coil removed and shunt coil in series with three microfarads and 2,000 ohms non-inductive resistance. Recording gear removed and light torsion spring attached to disk.

due to the distortion of the E. M. F. and current waves.

Table V gives observed and computed values for these curves.

Conclusions.—It would seem from the above that there is a decided need of an accurate power factor indicator in all large installations, but especially in those in which induction and synchronous motors are used together. This method of operation has been adopted by the Deering Harvester Company, where adjustment of the exciting current of the synchronous machine is

1. Symbolic Representation of General Alternating Waves and of Double-Frequency Products. C. P. Steinmetz, TRANSACTIONS, vol. 16, p. 289, 1899.

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made by means of a wattmeter, and at Butte, Montana[1], where adjustment is made from ammeter readings. The advisability of adopting this composite system is not in question here. We are considering merely the best method of attaining the end sought.

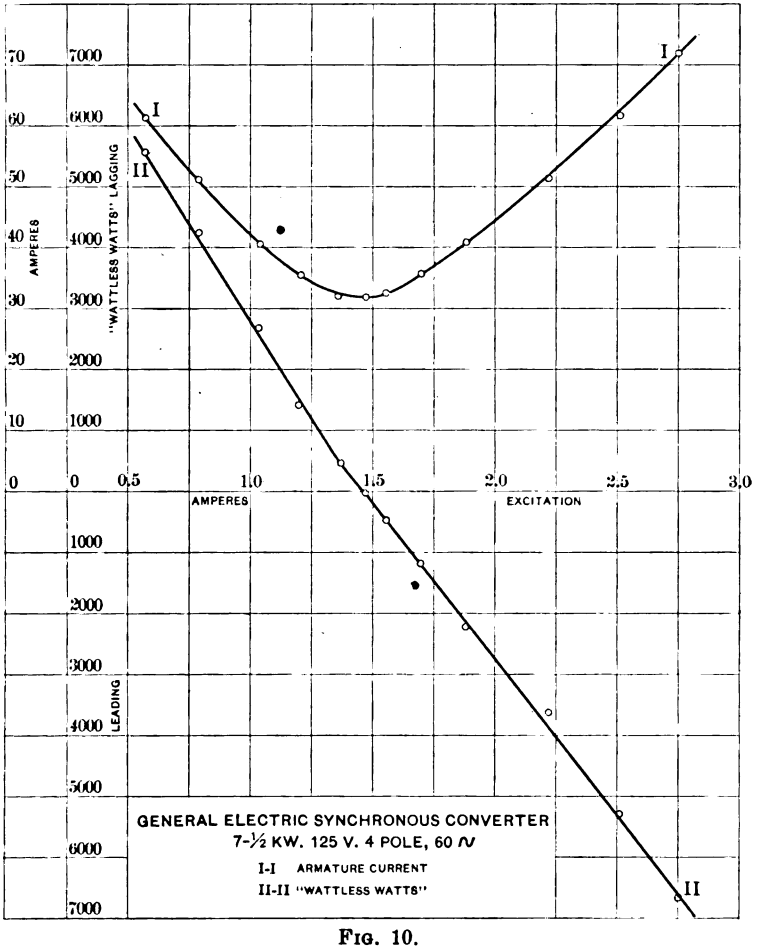

FIG. 10.

For accurate adjusting of the system the indications of the instrument should depend upon the values of φ or sin φ and not upon cos φ.

Instruments of the dynamometer or the induction type seem more suitable for operating conditions. If the meter be of the

1. Elec. Lt. & Power at Butte, Mont. J. R. Cravath, Elec. W. & E., vol. 37. p. 149. Jan. 26, 1901.

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dynamometer type the resistance of the pressure coil must be negligible if it is to be used on a single-phase system, as the cur-

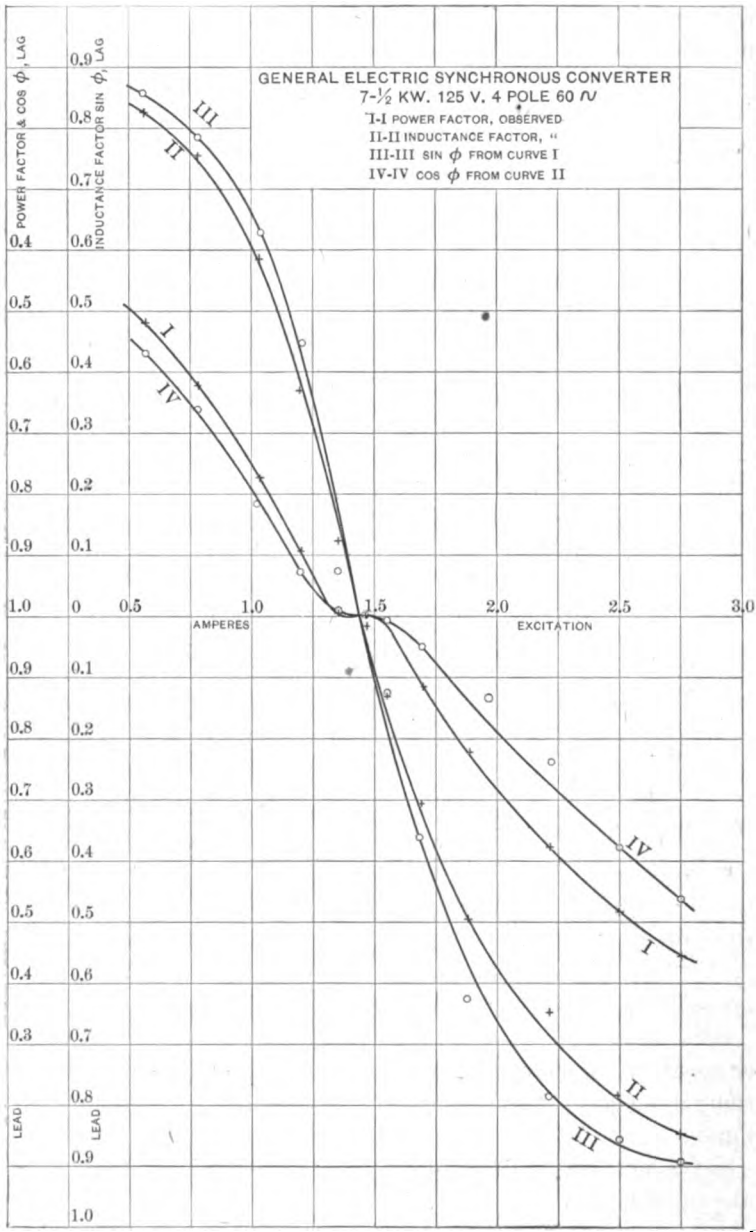

FIG. 11.

rent in this coil must be in quadrature with the E. M. F.

If the meter is to be used on a two or a three-phase system,

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the inductance of the pressure coil must be negligibly small, and meter connected in one of the methods described above. In this case care must be taken that the loads on the different phases be kept equal. In a two-phase system, unbalancing the phases will shift the E. M. F.'s relatively to each other. In a three-phase system, since the meters used are really wattmeters, unbalancing the phases will vitiate the indications of the instrument.

If the meter be of the induction type the inductance of the pressure coil must be negligible, since not only is it undesirable

TABLE V.

General Electric Synchronous Converter. 7½ K.W., 125 V., 4-pole, 60 ~, 2-phase. Input 3.5 K.W. per phase.

Wattless kilo-volt amperes.	Amperes armature current.	Voltage at brushes.	Amperes field current.	Phase relation.	Kilovolt amperes	Power factor.	Inductance factor.	sin φ computed from power factor.	cos φ computed from inductance factor
5.55	61.6	109.9	0.57	Lag	6 76	.518	.822	.855	.569
4.23	51.3	110.0	0.78	"	5.64	.621	.750	.784	.661
2.62	40.9	109.9	1.03	"	4.5	.778	.583	.628	.812
1 45	35 7	109 7	1.2	"	3 91	.895	.371	.446	.929
0.45	32 0	109.8	1.36	"	3.51	.997	.128	.077	.992
— 0.05	31.9	109.8	1.47	Lead	3.50	1.0	.014	.0	.999
— 0.45	32.1	110.0	1.55	"	3.53	.992	.128	.126	.992
— 1.20	35.7	110.4	1.69	"	3.94	.888	.306	.460	.952
— 2.22	40.9	109.8	1.88	"	4.49	.779	.493	.627	.869
— 3.65	51.3	110.0	2.22	"	5.64	.621	.648	.784	.762
— 5.30	61.6	110.2	2.5	"	6.78	.516	.782	.857	.623
— 6 65	71.9	109.8	2.75	"	7 89	.444	.844	.896	.536

to use condensers to compensate for this, both from their bulkiness and expense, but the presence of any reactance makes the deflection dependent upon the frequency. An attempt was made to improve upon the induction meter described above by removing the three-legged stampings of iron upon which the pressure coil was wound. The inductance was still too large for satisfactory working and as the condensers in the laboratory were not sufficient to compensate for this, it was necessary, to make up for this lack of capacity and to avoid the use of iron, to add an auxiliary inductance wound on a wooden bobbin. The instrument thus modified was found to be so sensitive to slight changes in frequency that it was impossible to use it with any degree of

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satisfaction in the laboratory. Any change of load on the prime mover would so change the reading of the instrument as to make its indications extremely unreliable.

Dobrowolski shows, in the reference given above, the application of his instrument for automatically adjusting the excitation of the synchronous machine so as to keep the power factor at unity at all times.

The use of an instrument of this kind emphasizes the fact that, when induction motors are used alone, the inductance factor is always a large percentage of the power factor. For instance, when the power factor is .85 the inductance factor, assuming sinusoidal waves, is nearly 62% of this. That is, for every kilowatt used by the motor, 620 "wattless watts" are, so to speak, borrowed. It would seem but fair that those who use induction motors should at least pay rental for the wattless volt amperes required. It is true this does not represent energy consumed, but it does, in a sense, represent energy borrowed and returned and the station must have sufficient capacity in generators to meet all such calls for loans.

The additional charge could be taken care of by over-compensating integrating wattmeters of the induction type, as suggested by Mr. Benischke. They would then read high on lagging reactive loads and low on leading reactive loads. This would put a premium on the use of synchronous motors as they, if not too greatly over-excited, help out in the regulation of the plant. The induction motor has so many points in its favor it can well afford to pay for what it needs—a large wattless component of current.

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Eighteenth Annual Convention.

Discussion at Buffalo August 21st. Papers by Lincoln, Haskins, Davis and Browne.

Mr. W. S. Barstow:—In the last paper, that of Mr. Browne, I was very much impressed, as a central station manager, with the special attention paid to the wattless energy in the starting of the motors. In large central stations, the one thing which is retarding to a very marked degree the development of the alternating current both for railway and for lighting, is the fact that you are required to have in the station such a large capacity compared with the horse power of the motors that are installed, as against that which it is necessary to carry with a direct current installation. Whether it will be possible for the station to secure an income from this "borrowed current,"—that is quite another matter to consider. In almost all cities there are both systems in existence, and the cost of the two systems, direct and alternating, are continually compared; so that we have the commercial problem of still getting a rental for the borrowed energy used in starting the motors, and at the same time keeping the customer's bill so that it will not suffer by comparison with that for the energy used in direct current motors. In other words, there are many cases all over the country where in one block a customer will use direct current service and in the very next block, or a short distance away, another customer, a friend of his, will have an alternating service, and they often compare their bills. That is one objection from the commercial side, but still I think that the central station ought to receive, in some way, as Mr. Browne has so appropriately put it, a rental for this "borrowed current."

The President:—I quite agree that it is not desirable to permit customers to receive this wattless power for nothing, but I do not agree with Mr. Barstow that it is inherent in andan essential of the alternating system, and of the alternating motors to overload the station in starting with excessive wattless currents. The wattless currents of the alternating motor especially when starting, are largely an incident due to the neglect of the station manager to guard against them. It depends entirely upon the motor whether excessive wattless currents exist. The alternating current induction motor can be made to start and operate with very moderate wattless current, but then it becomes slightly more expensive, and consequently if the station does not exercise any supervision and control, the customer buys the cheapest motor, and the manufacturer of motors is obliged to supply it, and such a motor will in starting take three or four and more times its full load current. This rather unfortunate feature is responsible for much of the trouble with excessive wattless currents and poor regulation in alternating motor circuits.

In the paper on "Power Factor Indicators," by Mr. Browne, is mentioned a way of charging for the wattless current by over-

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compensating the recording meter. I had some experience with that. Quite some time ago, I believe in 1894, when a fairly large system was changed to alternating, a large factory was to be operated by induction motors, instead of the continuous current motors used before, which were of any ordinary kind. The bills for power with the induction motors were found very small compared with those for the continuous current motors, and the customer was willing to pay for the wattless current. The manner in which this was accomplished was by inserting in the potential circuit of the recording wattmeter an inductive reactance (instead of making the potential circuit as non-inductive as possible, as customary) adjusted so as to charge the desired percentage of wattless current, I believe 25 per cent. In this case the meter read high at highly inductive load, right at non-inductive load and low at anti-inductive load.

As an objection to the power factor indicator there has been mentioned the error due to the current in the potential coil lagging less than 90°, in consequence of its resistance. This objection has been overcome by dividing this current again into branch currents displaced from each other, for instance, by shunting the potential coil by non-inductive resistance. Hereby the potential current, as the more lagging branch current, can be adjusted to perfect quadrature with the main E. M. F.

MR. HASKINS:—I wish to remind the INSTITUTE that the question of charging (in the meter) for idle current was quite fully discussed before the INSTITUTE as early as 1897, at Greenacre. I think it was the sense of the discussion, that it was highly desirable, and perhaps feasible, to adopt a system contemplating an overcharge (on the watt basis) for inductive loads.

PRESIDENT STEINMETZ:—I am quite sure there is a good deal more to be said on the question of meters, and that many of you can give us a good deal of valuable information—for instance, Mr. Dunn.

MR. H. W. BUCK:—Referring to Mr. Lincoln's paper on the subject of the synchronism indicator, I have seen this device in operation at the plant of the Niagara Falls Power Company for some time, and from a practical standpoint I think the device very valuable. In the old days of small alternators, where the inertia of the revolving armature was very small, almost any device could be used as a synchronizer, for if the armatures were not in strict synchronism when paralleled, it took a very small amount of electrical power to jerk the armatures into step, so to speak, but with the large direct connected alternators which are at present being used, the amount of power required to synchronize the machines is something enormous, and unless the machines are thrown together at the point of exact synchronism, it takes a very large amount of synchronizing current, which is a severe electrical shock to the system, and a very great amount of mechanical power, which is a great strain on the

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units. So that much more accurate methods of synchronizing are at present demanded than formerly, and for this purpose this synchronizer which has been described is, I think, the best device which has as yet been developed. A voltmeter can be used as a synchronizer, but it is not satisfactory, for the reason that the low readings of an alternating current voltmeter are not at all accurate, and therefore the exact moment of synchronism is not indicated, and the error is very considerable. Another objection to the use of a voltmeter is that the amount of power which operates the needle of the voltmeter is limited, and it cannot therefore be made very large. Mr. Lincoln's synchronizer which is practically an alternating current motor, can be made any size, so that the needles can be made very large and can be seen from any part of the power station, which is certainly very desirable. When alternators are thrown in parallel, a man is almost always stationed at the throttle of the engine or at the controller of the water gate, so it is very desirable to have an instrument which he can see, so as to adjust his admission of power as the machines accelerate or retard, and this function is very satisfactorily met by the instrument which Mr. Lincoln has described.

Mr. Gano S. Dunn:—President Steinmetz has asked me to contribute something to this discussion, which I am loath to do, because my principal interest in it is not on the part of meters, but is developed by the remarks of Mr. Barstow in regard to the wattless or borrowed current, in central stations. My contact with such work has been in comparing the starting currents of alternating current motors with those of direct current motors, and as some of you know, my work is with the direct current altogether. It is a fact, especially where motors are called upon for more than their normal torques, that the borrowed currents are very great. I have been unable to harmonize the amount of current that the manufacturers claim will be taken in induction motors with the amount of current that it is actually reported they do take. For instance, certain motors with which I am familiar are claimed to start with about 4.4 times their normal running current, whereas the testimony of the station men that have these motors running on their circuits is that they take nearly double this amount; and practically the evidence that I have is that the induction motor starting currents are normally very excessive. As Mr. Barstow pointed out, not only does this make a service delivered by the station that is not paid for, but it introduces other difficulties, such as bad regulation, affecting lights, neighboring motors, etc., which are very serious, and I believe that it is true to-day that these large starting currents and the large wattless currents necessary to secure a large torque are among the principal things that are impeding the development of induction motors, and any improvement that would remove these impediments would see the induction motor far ahead of where it is now.

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MR. RALPH D. MERSHON:—I cannot agree that it is necessary to have an excessive starting current in the induction motor. There is no reason why the excess of current over that of the direct current motor should be more than 10 per cent., if that, and there is no reason that I see why there should be any limit, within reason, to the starting torque of the induction motor. The motor having the objectionable qualities mentioned by the gentlemen who have spoken, is the motor with the closed circuit secondary. It is true such a motor does start with a large current, the amount of current depending upon the torque required, but if a motor of that sort is installed, it is installed because of the desire for the simplicity and the reliability that such a motor gives, and part of the price you have to pay for that is a larger starting current than would be taken by a direct current motor. If on the other hand there be installed a motor without the closed coil secondary and with slip rings enabling one to introduce into the secondary at starting a resistance, then the motor may be started in a manner and with a result very similar to that of a direct current motor.

The regulation of the system when a motor is started with resistance in its secondary, should be just about as good as with the direct current motor. A motor starting under those conditions will have, it is true, a power factor somewhat less than unity, but the difference is too small to be of consequence. As regards the regulation of the supply system after the motor has begun to run and carry load, I think you will find—in fact I know you will find—that the variation in voltage will be less as the load on the motor varies than it will be with the direct current motor.

It does not seem to me that you can charge for wattless current. The customer is paying for power and ought to be charged only for power. The difference which the wattless current will make as regards the capacity of your generating station is not so great as it is ordinarily thought to be. The motor load is generally a comparatively small proportion of the total output of the station at the time when the lighting load is heavy. At the time when the lighting load is light the motor load is even then, in general, considerably less than the total output of which the station can take care. When the lighting load is heavy, the lighting load itself brings the power factor of the system up to a very considerable figure, so that the sacrifice as far as capacity is concerned is comparatively small. But suppose you make an objection to that sacrifice in capacity, small as it may be—what are you going to do about it? Are you going to supply power by direct instead of alternating current? If you undertake this, under most conditions, the extra apparatus, extra care, extra operating expense and extra maintenance, to supply direct current power, will more than overbalance the interest on the investment for the increased capacity which would be required in your generating station by reason of a power factor somewhat less than unity.

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MR. C. F. SCOTT:—In the present somewhat random discuss on several statements have been made concerning the induction motor. The "squirrel cage" form of secondary winding has been suggested as the cause of more or less of the troubles which come to the central station man. It has been asserted that a certain motor requires between eight and nine times the full load current for starting. One would hardly be justified in concluding from this statement that all induction motors under all conditions require a starting current in accordance with the figures reported. Was the motor referred to one which can properly be taken as a type or representative of all induction motors? Was it operated under normal and proper conditions? Were the starting devices properly used? What was the torque actually developed? The statement standing by itself gives no more valuable information than would the assertion that a direct current motor may be started in such a way as to take an initial current ten or twenty times its full load current.

In the preceding discussion it has been implied that the starting current of an induction motor considerably augments the amount of power required and the resulting meter readings. It should be evident, however, that an ordinary constant speed motor requires but a few seconds for starting, so that the total energy taken during a day's run will be scarcely affected whether the motor requires its full load current or ten times that current for a few seconds in starting.

The general term "induction motor" as was pointed out by the last speaker, covers the two varieties of motor, the one with a short-circuited or a "squirrel cage" winding and the other with an adjustable secondary resistance, the latter permitting the lower starting current, but having the disadvantage of being more complicated in construction. What the last speaker pointed out is worthy of being emphasized, that the mere point of starting current is not the whole criterion by which a motor is to be judged. Its construction, its simplicity in operation, its nonliability to get into trouble, its behavior under extreme and emergency conditions—all these things are points that should be taken into consideration in the broad study of the performance of a motor.

With respect to the expense of running motors it may be noted that the items of cost of direct current motors and of alternating motors are not of the same kind. If we grant that the induction motor on account of its magnetizing current or other reasons may on the whole require a greater first investment, yet on the other hand the cost of maintenance of commutator and brushes of the direct current motor, the greater expense incurred for maintenance and for repairs, necessitated by wear or accident will in general far more than offset any additional first investment which might be required for installing induction motors.

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MR. DUNN:—The topics that we are discussing are meters and power factor indicators, and when I made my first remarks I announced that it was with hesitation, because they tended toward the subject of the relative values of direct and alternating current motors. Mr. Mershon, and also Mr. Scott, have made a number of statements, that I feel compelled to deny, but I do not feel that this is the proper time or place to discuss them, and therefore I wish to remark that I do not accept their conclusions, and file an application to discuss the subject at some other time with those gentlemen, if I may have the privilege.

THE PRESIDENT:—I do not think we are so far out of the way in discussing somewhat in connection with to-day's topics the question as to whether the induction motor gives rise to excessive currents or not, because when discussing power factor indicators the first and most important question to determine is, whether such instruments are necessary at all. If the power factor is sufficiently close to unity, so that it does not need to be considered, and if the excessive wattless currents are harmless, if existing only for a short time, then we do not need a power factor meter. So it is quite desirable to consider, whether conditions exist in alternating current systems which should be guarded against by a power factor meter; and it seems there is a disagreement of opinion in this matter. According to Mr. Mershon and Mr. Scott, there is no need of a power factor meter, because the power factor is usually high enough, and where it is not high enough, it is low for a short time only, and it would do no harm; and even if it is always low, the regulation of the system is good enough. Mr. Dunn, however, contends that the induction motor is vicious in the current it takes; and you have to put in some instrument to make the customer pay for the excessive current. Personally I am really somewhat inclined to the opinion of Mr. Mershon, that the induction motor can be built so that it will require no excessive current in starting, although I would enlarge upon Mr. Mershon's statement by saying that that does not necessarily imply sliding rings, or collector rings, but the starting rheostat can be carried by the revolving motor armature, together with its operating switch, which may either be automatic (centrifugal) or hand control.

The characteristics of the induction motor form one of the topics of to-morrow's program, and since we have some time to spare to-day, but will probably be crowded for time to-morrow, I see no objection to anticipate this part of to-morrow's program. Therefore, I think it quite desirable that Mr. Dunn should make his statement opposing the statements preceding his last remarks. While, as stated, the induction motor may be made so as not to require excessive current in starting, that is, to start with not more than full load current, when giving full load starting torque, this performance is not up to the continuous current motor, where a heavy starting torque is required. Under conditions where

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good regulation of the system is needed, with frequent starting, as in our larger cities for elevator service, continuous current motors have been built for years, which give a starting torque exceeding full load torque, while consuming less than full load current, and no induction motor has ever done that, nor ever will.

I will call on Mr. Dunn to supplement his statement.

MR. DUNN:—There is a tendency to force an antagonism between direct current and induction motors which I wish to deprecate. But the statement often made that for all purposes induction motors are more satisfactory than direct current motors I most formally and emphatically challenge. I yield to the induction motors the credit for their splendid properties, their simplicity and the fact that where our great systems of to-day are becoming systems of high-tension transmission and low-tension distribution, they often offer advantages that direct current motors do not. But the question of starting current is only one of the objections to induction motors, there are a number of others. If the statement I have mentioned could be maintained, it would mean that induction motors are as subject to speed control, that they are as efficient at all loads and that they are as capable of exerting torque as are direct current motors, also that their maintenance is so much lower that the saving in their operation in the long run more than pays for their greater first cost. Now, as I look back over these claims there is not one of them that I am not willing to combat.

This is the declaration that the President desired me to make.

MR. MERSHON:—The gentleman has said some things implying that a claim had been made to a greater suitability of the induction motor for all kinds of work. I do not think a statement of that sort has been made thus far. There are unquestionably conditions in the present state of the art under which a series direct current motor may be used more advantageously than the induction motor. I do not at this time recall any condition under which I would admit that the direct current shunt motor can meet the requirements better than the induction motor, unless it may be one where the voltage of the generator is controlled in order to control the speed of the motor.

As regards some of the special uses where the series motor gives better results, such as elevator work, as referred to by our President, under some conditions the series motor is very greatly better, but even in the case cited I will not agree with his statement in its full strength. I should want to dilute it a little bit. In shop equipment, there are some conditions where direct current is more advantageously used than the alternating; and in that line of work I might add an exception to that I mentioned a while ago where the direct current shunt motor might be more advantageously used than the induction motor. It is that where a number of voltages are made available so that the shunt motor may be operated at any one of a number of speeds but at any

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one speed will act as a constant speed motor. The cases where the equipment necessary for such service is justified are, I think, few.

As regards the question of first cost, the induction motor is more expensive than the direct current motor. With regard to the question of maintenance, durability, care of operation, I will put the induction motor before the constant current shunt motor every time, no matter what the service is. I have seen them operate and continue to do so under the most extreme conditions, receiving abuse under which the direct current motor could not exist. I have seen them in use in stamp mills, with absolutely no protection, with quartz dust falling in every direction, quartz dust getting into bearings and windings, and, by the way, the motors of the case of which I am speaking, the worst case that I know of, were motors with collector rings, and the collector rings were being continually cut by the quartz dust. These motors were on foundations which were not worthy of the name, and overloaded to the point where it would seem as though they must burn out every minute. I do not think there is any question as to which motor is the more durable and which will give the less trouble and cost the less for maintenance.

MR. DUNN:—We seem to be taking specific cases, which are easier to discuss. I understood Mr. Mershon to say that excepting the conditions of speed control obtained by varying the voltage of the generator, he knew of no one point in which the induction motor was not superior to the shunt wound direct current motor. Let us assume, for the moment, that this control is not an important feature and pass to the other points. I have been going over in my mind some data of a certain size of direct current motor on which I personally made some tests with induction motor comparisons in view, and I do not see how, if Mr. Mershon and I accept the same data, his statement can stand. For instance, in regard to the starting torque. The starting torque claimed by one of our manufacturing companies for its induction motor of the same size as the direct current motor that I have tested, is 2.2 times the normal torque. The corresponding direct current shunt motor I started with 6.4 times its normal torque. The starting current for this same induction motor is claimed to be 4.4 times the normal running current. The direct current shunt motor required for the same torque only 2.4 times normal running current. The efficiency of the direct current motor was higher at full load than that of the induction motor, and at overload vastly higher. The direct current motor hung on to its work and did not stall until it was loaded to 6.4 times normal torque. The induction motor fell out and gave up the fight at about 2.7 times normal torque. [See page 336, discussion communicated after adjournment.]

With regard to the motors that worked so well in quartz dust, which Mr. Mershon cited as a remarkable fact. I have had

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direct current motors, a whole plant of them, working for a long time, in graphite dust, and some of them in places where the graphite settled 1/32 of an inch over night, and this plant is giving entire satisfaction. The only trouble that has been experienced has been, not at the commutator, but at the rocker arms, and has been due to slightly faulty insulation where the brush studs went through; an easily corrected trouble. Now, I am of the opinion that when it comes to a question of dust, the direct current motor is ahead of the induction motor on account of its larger air-gap. I have known cases where induction motors have stalled from running in dusty places because of their small air-gaps filling up with dust and causing them to jam, and, contrary to the general opinion, it is impossible completely to encase the induction motor, because the sacrifice of capacity is then too great.

One would be inclined to think that induction motors were free from troubles, but they have troubles of their own that the direct current motors do not experience.

With regard to the question of maintenance, it is very difficult to get accurate figures, because in this country the plants in which motors are installed are usually so anxious to get their motors running and turn out their work that they have no systematic means of keeping account of the maintenance expenses. But I would say that most of the figures given for the maintenance of direct current motors are taken from records that have been kept for a number of years past, and they apply to the older and imperfect types of the direct motors and not by any means to the perfected modern direct current motors that you would buy if you bought them to-day. The direct current motor has been progressing without attracting attention, and it has been progressing in many ways as rapidly as the induction motor. To-day the commutator troubles of the direct current motors of the most advanced design are reduced to only a fraction of what they were a few years ago. If you are comparing induction motors with direct current motors, compare to-day's motors of each type, and do not compare direct current motors of a few years ago with induction motors of to-day.

Now, with regard to the feature Mr. Mershon excepted, namely, the controllability of speed—this is not a small matter nor one that will permit being excepted. It is a vastly important matter, and as far as the equipment of machine-shops goes, I consider it a deciding matter, because machine shops, wherever you find them, require from one-third to one half of their work to be of controllable speed character; and if you can offer a motor which, without sacrificing efficiency or stability of speed, will give you a speed controllable at will from the very lowest values to the very highest, you there offer an advantage enough to offset the advantages claimed for the induction motors; and to cap the climax, the direct current systems are considerably less expensive because of

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the smaller capacities required in the motors and because you are not at the necessity of providing for the borrowed current which you have to provide for in the wiring, generators, instruments, etc., when you put in an alternating plant.

MR. W. S. BARSTOW:—When I started this discussion I did not realize how it was going to end. From the central station point of view I think that the "direct alternating" current motors are the only motors to use. There was one matter I mentioned before that I might perhaps speak of a little further so as to avoid any misunderstanding. I mentioned the fact that from the central station point of view it might be a good thing if there was some way of the station receiving returns for this borrowed energy. I meant that more in the form of a penalty. With direct current motors the station has no trouble, because the direct current motor rapidly reached a permanent development and has been in use for many years. The alternating current motor is more or less in a transitory state. We find in central stations that many of the customers, or would-be customers, buy motors second hand on account of the higher cost of the new alternating current motor over that of the direct current motor. When they buy these motors from the jobber it is almost impossible for the central station to carry out faithfully the specifications for connecting motors to the system. The customer will come to the station and inform you that he has already bought a motor. You investigate and find out that it is an old style induction motor which takes a large amount of starting current. You have got to take either one of two positions. You have either to refuse to connect the motor to the system, although he has already bought it, or you have got to connect it and make some special excuse for so doing. That is the commercial difficulty. If a customer notifies the company that he is about to purchase a motor, that difficulty is easily overcome, as almost all central stations these days have specifications for the connection of different devices to the system. When I mentioned the fact that it would be a good plan to secure some return for the wattless current, I had it in mind as a penalty for the customer who bought motors of a cheap or antique type and who still persisted in trying to force the station to waive its requirements and connect him to the system. If all customers could be given to understand that even if they were connected they could save money by buying a modern motor in the first place, that difficulty would be removed to a very large extent. But where they can appreciate no difference, except as it aids the central station, they often absolutely refuse to make any change; and, as I say, the station has the choice of violating their own requirements or of flatly refusing to connect the customer.

MR. MERSHON:—In regard to the question of absolute cost in the installation of the direct or the alternating current motor, I do not want to go into that subject at all. I will say, however,

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that in a great many cases, I think in most cases, the advantage to be gained by the use of the alternating current motor justifies paying some more for it. I won't say how much.

Mr. Dunn spoke of two motors which he compared, one presumably a commercial alternating current motor; another presumably a direct current shunt motor. Whether it was a standard one or not, I do not know. What was the temperature rating of that motor, Mr. Dunn?

MR. DUNN:—The other motor was a standard motor taken directly out of the storeroom, with no change or modification made whatever.

MR. MERSHON:—What was the temperature rating?

MR. DUNN:—Forty degrees, centigrade rise, under continuous load.

MR. MERSHON:—As regards the question of efficiency; in this particular case that Mr. Dunn cites, the efficiency was greater in the case of the direct current motor. That is not very surprising. If you compare the direct current motor lists of different manufacturers, one of whom makes presumably just as good a motor as the other, you will find that the efficiencies of one list will be the higher for some sizes of motors, and the lower for the other sizes. This will be true also with the alternating current motors, and it may have been in this case that Mr. Dunn unwittingly compared a comparatively high efficiency direct current motor with a comparatively low efficiency alternating current motor.

The motor to which Mr. Dunn referred was evidently a motor with a closed coil secondary, a "squirrel cage" winding. For the service contemplated for this motor in which it was to give six times its full load torque, the motor was not the right one. It should have been a motor with rheostatic control. As regards the question of six times full load torque, where such is necessary —it is not necessary in many cases,—but where such is necessary, it can be obtained with the alternating current motor. The accessory apparatus for obtaining it would be more or less special, it is true, but I think most of you will agree that the requirement of six times full load torque in a constant speed direct current motor is a more or less special condition, and that it would require accessory apparatus which would be more or less special. You certainly would not use the same mechanism in the case of a motor which was to start with six times its full load torque, as you would with a motor which was to start with full load torque, or $1\frac{1}{4}$ times full load torque.

As regards the specific instance which I cited of an induction motor running in a stamp mill and subjected to quartz dust, it was stated that it ran under conditions under which a direct current motor would have fallen down. This statement involves, of course, the element of personal opinion, but, as a matter of fact, the conditions under which those induction motors were running, with no attendance—for they had none, absolutely none

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—were such as no direct current motor could have withstood. As far as the graphite factory is concerned, I do not know the quality of the graphite, but it seems to me that good graphite would cause no injury to an induction motor, on the contrary it might aid in the matter of lubrication, whereas the quartz mill would not be a very nice place for any kind of a motor. I do not think there can be any question about it, that the chances for trouble in the case of a sliding contact, where you have simply a slip ring, are very much less than in the case of a commutator where the contact is continually changing, and by reason of which change there is continual chance of trouble.

THE PRESIDENT:—The discussion has drifted toward the relative merits of the continuous and the alternating current motor, and both sides have been very ably represented; yet it seems to me that neither of the two sides has been able to prove that either type of motor is universally superior, but that both have their good features, in some instances one being preferable, and in some instances the other; for instance, when running in an oil refinery or a powder mill, use the induction motor, and when running a railway, as a rule use the continuous current series motor. Between these two extremes there is an enormous range of conditions where each motor can find its place.

But there is one point which Mr. Barstow brought out, that these specifications should be made, to guard against the use of any inferior motor, and to secure a motor suitable to the conditions. The ordinary motor is very suitable to drive a mill or factory, but in a close regulating alternating system it is not always desirable. Specifications regarding motors have been made in continuous current systems—and I could tell a tale about them, at the time when I was connected with electric elevator motor design, and we had to develop a constant speed motor giving more than full load starting torque with less than full load current. We produced this by adding a powerful series field, which took the part of the starting rheostat, and in starting was gradually and in sections cut out. But I am sorry to say that in the alternating current systems such specifications have not always been maintained, and alternating current motors have been installed of a type which should not be installed, and it is for that reason that a discussion such as this as to the relative merits and demerits of the two types of motor is very useful, by drawing our attention to the necessity of considering the matter, not as a thing by itself, but as a part of the system, and to be chosen to suit the remaining part of the system, and not to be chosen at random from the infinite variety of types available on the market.

There seems to me, therefore, some reason to assume that the question of power factor is important, and that power factor meters are of use and value. Thus we come back to the discussion of meters; and as Mr. Hering has given this matter quite a good deal of attention, I should like to hear from him about meters and his experience with them.

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MR. HERING:—I am sorry to say that I cannot contribute anything new to the discussion of the subject of meters. I am glad to see that the value of wattless current indicators is beginning to be recognized, as I think they are very important instruments. Regulation, especially of rotary converters, and other desirable results can be obtained by a suitable wattless current indicator, more directly and with less difficulty than with only the usual instruments from the readings of which the wattless current can be obtained only by calculation.

If I may be permitted, for a moment, to go back to the other part of the discussion, however, I would like to cite a case which is of interest concerning the starting torque of induction motors. I had the pleasure last year of taking a ride on a three-phase railroad in Switzerland, the only one which is run under steam railroad conditions. The cars were all of the large steam railroad type, and there were about three or four cars to a train. I refer to the Burgdorf-Thun Railway. I rode with the motorman, reading the ammeter as he started the train, and noticed that he seemed to cut out the starting resistance of the induction motors so as to keep the starting current about double the normal and no more.[1] The ammeter seemed to be his guide in handling the controller. The train was therefore started with no more than double the normal running current, which I think is a very good result. To be sure, the train did not start so suddenly that the people were jerked off their seats and had to expend a lot of energy in keeping their places, but I think that is an advantage rather than otherwise.

MR. MAILLOUX:—I would like to state, exactly on that same point, that Mr. Arnold and I were on the same road either a day or two before or after Mr. Hering; but the motorman may not have been so careful, because I noticed that the motor did not start with quite the regularity and uniformity that Mr. Hering speaks of. The motorman did not know that we were observing an ampere-meter which was at the other end of the car and which gave all the readings; and these readings fluctuated quite considerably. My impression is that the starting current was much more than twice the running load.

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1. Since the above discussion took place I found a published statement according to which the current is even less than what I had noticed. In *Engineering* (London), November 1, 1901, p. 626 there is a communication by Brown, Boveri & Co. (who designed and constructed that road), in which the following statement occurs: "As regards the simple resistance control, this is not nearly such a bad system as some people would like to make out; it may be of interest to your readers to hear in this connection that on the Burgdorf-Thun line we start heavy trains on the level, with an acceleration as high as 1¼ feet per second per second, *without taking more current from the line than the normal current*." The italics are mine. I now recall that when I made my observations the train was ascending the gradual rise on the southern part of the line, which accounts for that larger starting current.—C. H.

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I do not quite agree with Mr. Mershon as to the unfairness of charging the customer what Mr. Barstow has so aptly termed a "penalty" for the abuse of the current or because it is used under improper conditions. The fact is that a penalty system is already in use regularly in most central stations. We have negative penalties in the various forms of extra discounts which are given to customers who use current during the day time. The man who uses it only at night pays more in many cases. The man who uses more per lamp or per month also gets an extra discount, so that the man who does *not*, is really paying a penalty. It seems to me that the plant is subjected to the abuse of extra generating capacity, so to speak, by the party who puts an extra wattless power demand on the line, and it ought to be paid for just as much as the failure of the customer to raise the load factor of the station is susceptible of a penalty and is usually taxed by an extra charge. I have had some practical experience with cases showing the necessity of power factor indicators and also of a penalty for introducing excessive wattless current. One was a small plant of somewhere between 150 and 200 K. W., which for convenience, owing to the distance of distribution, used alternating current at about 2000 volts. The service was a mixed one, including lighting and power; at times mostly lighting and at other times mostly power. There was one customer who used about 75 H. P. in motors of two or three sizes, and although the motors were to be run only or mostly during the day at a time when there was very little or no lighting load, yet it would occur repeatedly that the starting of one 30 or 40 H. P. induction motor would not only stall the line but actually blow the fuses at the station. This typifies and illustrates the necessity and the equity of a penalty for an excessive wattless current. These motors were, I understand, of the very kind which are said to take the least current, owing to the fact that they have slip rings and internal resistance, or a variable armature resistance. They may have been greatly improved in the three or four years which have elapsed since; but the fact remains that oftentimes the starting of a 40 H. P. motor has thrown wattless current enough on the line to blow the fuses of a 150 or 175 K. W. unit; and this occurred so repeatedly that finally the system had to be abandoned and direct current had to be introduced instead. I have also seen many cases of installations, even on a very large scale, of plants having as much as a total of 2500 H. P., where the use of the alternating current was entirely inadmissible, although the units in service were large, the average size of motor being somewhere between 25 and 35 H. P., the reason being, simply, that they could not obtain that variation and regulation of speed which is essential in most cases where power is applied on an extensive scale in factories and for industrial purposes. There was a very interesting discussion on this very matter just about one year ago at Paris in the joint meeting of this INSTITUTE and the Institution

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of Electrical Engineers of Great Britain, in which many representative men of both countries present took part. I think the conclusions drawn from that discussion were to the effect that there is no one system which is applicable to all cases, that the non-synchronous motor, or induction motor, has a sphere of utility quite its own, in which it is preferable. Of both it may be said that there are uses where cost is not the independent variable; where there are other things which are of stronger import than the cost. So that, if we are going to compare motors and are going to compare them on the score of cost, we should take cases in which cost is the independent variable. If we are going to compare them in cases where absolute safety is the prerequisite, such as in the case of a powder mill, cited by our honored President, then of course we have another condition, where cost is entirely out of the question, where safety must be had at any cost and under any circumstances, a case in which the bare possibility of a spark from a commutator is a reason for excluding, of itself, all thought of anything but the induction motor. Those may be said to be cases which are entirely *sui generis;* as such they call for specific treatment. I am entirely disinterested; I have made interesting and useful installations with both systems. I love to apply each system to that purpose for which it is best suited, as I think every conscientious engineer does and should; but I do not like to see a spirit of partisanship induce one to compare things which cannot be compared. It is hardly fair to either system to undertake to establish a comparison between two things under conditions under which they cannot be compared any more than stones can be compared with eggs.

MR. MERSHON:—I want, Mr. President, to endorse the last remarks of Mr. Mailloux. One reason why I have taken up this matter is, that discussions before this INSTITUTE and elsewhere have left the impression with many that the alternating motor had no right to live and that there was no use for it; that about the only place for it was the junk heap, and that the direct current motor was the only thing to be used. That is one reason, as I say, why I have taken up the question of the alternating current motor. Beside that, I think it is one of the most beautiful pieces of mechanism we know of, from every standpoint. I will admit, as I did a while ago, that there are some uses for which the direct current motor, and especially the series motor, is better adapted than the alternating motor, and in those fields the alternating current motor has not very much chance; but there is a common ground, and there is a ground furthermore, that is not common to both, but which is pre-eminently the field of the alternating current motor. Throughout this discussion I have had in my mind generally the idea of the constant speed motor, any motor which normally operates at constant speed. It is better to put this limit on such a discussion as this one, because it simplifies matters since entering into the variable speed field

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means more or less complication, not only in engineering but also in discussion, no matter which system you take up.

MR. SCOTT:—My good friend, Mr. Dunn, made the statement that what he was contending against was the proposition that for all cases, for universal application everywhere, the alternating current motor was the best, and that the direct current motor had no place where it was to be chosen against the alternating current motor, implying, as I took it from his language, whether intended or not, that I had taken the position that the alternating current motor was the thing to use everywhere. I very readily and heartily agree with Mr. Dunn in the position, which I have always held, that the direct current motor has its place and the alternating current motor its place. As has just been stated, each has its own field, its own characteristics, and ought to be selected for its own work. But what is its own work? The two extremes are well defined, but it is this middle ground, this dividing line, on which we are somewhat at variance and on which the good judgment of the engineer—not alone the manufacturing engineer, as his judgment may not be good—but of the consulting engineer, of the general electrician, must come in in deciding the relative merits of these motors. As I recall, one of the statements made was that wherever an induction motor could be used, a shunt motor could be used with equal or better success. Let us for just a moment make a common sense comparison between the two motors themselves. In the direct current motor, one of the most prominent elements is the field winding, made up of large coils of fine wire, which must be well insulated to prevent injury from "field discharge" and which are sometimes liable to overheat. The alternating motor has no field winding at all. Another prominent thing about the direct current motor is the brush holder, "a little thing which could be easily corrected if it did not get out of order," and brushes do wear. The alternating current motor has no brushes and no brush holder. The direct current motor has a commutator, the induction motor has none. The direct current motor has an armature winding, consisting of a large number of coils, properly connected. The alternating current motor has a primary winding for receiving current which corresponds closely to the armature winding of the direct current motor. Both have those windings, but one is on a revolving armature frequently held by band wires and connected at a hundred points to the commutator. The other is stationary, in an outer shell, with only a few connections to the outside line. I confess that my electrical experience has been such that to my mind there is a difference between these two constructions, and that the direct current motor is by no means the equal of the alternating current motor in any of these respects.

Reliable general data as to cost of maintenance is difficult to secure. As has been stated, records of maintenance are fairly well kept with direct current motors. They have been longer in

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use and records have come to be a matter of form. With regard to the alternating current motor, records of maintenance are perhaps not so available. In some cases there is no record of cost of maintenance, as has been stated by engineers who have been running the motors for quite a while, and who point with pride to that fact.

Complaint has been made against the alternating system that the generators must be larger in order to accommodate the extra current, the "wattless" current. Sometimes the same machine is used both for direct current and alternating current, the commutator being at one end and collector rings at the other. Therefore, to make an alternator out of a direct current generator, you may simply make connections from the winding to collector rings and leave off the commutator, which is one of the very large elements of cost in the direct current generator. The saving thus effected can be applied in such a way as to give an increased output from the alternator and thus make it able to deliver the exciting current which is needed by the motors.

Referring again to the cost of power; in a manufacturing establishment or a mill, the total cost of power, including fuel, interest and maintenance, often does not exceed a few per cent. of the total cost of manufacture. A very large increase therefore could probably be made in the cost of the power plant, if greater simplicity and greater reliability can be obtained in that way.

In about all that has been said in this discussion this morning, it might be inferred that the alternating current motor was merely a possibility of the future. The alternating current does not, however, lie wholly in the future. As a matter of fact such motors are in use by the thousands. Those with "squirrel cage" secondary windings constitute the principal output of alternating motors of the Westinghouse company, and the number of these motors now in use runs up into very large figures—I have not the exact statistics in mind—but if I remember correctly, there are, in addition to many other uses, something like 100 industrial plants which are running with induction motors.

THE PRESIDENT:—Much more than that.

MR. SCOTT:—Mr. Steinmetz, with reference to another company, adds to the number. The motor has established its place, and it is a notable feature that where alternating current motors have been used they are in such high favor that when extensions are being made or other plants of the same operating company are to be installed, the choice is quite sure to be in favor of alternating current motors.

MR. F. S. HOLMES:—This discussion reminds me of an experience of some of our number at Alt Nuernberg last evening at supper. They were not apparently used to American methods, and I heard one of them say that $13 for that supper was a "darling." Now, there is a wish among men to get an equivalent for what they spend. We have been told by the people

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representing the induction motor that it has no commutator and no field winding. In fact, there is very little to this motor except price. For this reason, gentlemen, the manufacturing contingent of this country declines to take induction motors in isolated plants, where current is not distributed long distances. In Europe the induction motor is cheaper than the A. C. motor. For the present condition of affairs in America we must thank the U. S. patent office and combinations.

There are two or three objections to alternating current stuff beside price. I speak now not of long-distance transmission but of local work in factories. A hanger must be limited in drop because its ceiling has a limited height. The speed of induction motors has been high. Power should be applied directly, and not by a counter-shaft to a main line. It has been very difficult to find motors of the A. C. type which could be hooked up directly to shafting without very long hangers. That is an objection that is disappearing as we get the frequencies reduced.

Again, if I go to a manufacturer of direct current apparatus and say, "Build me a motor to run at 353 revolutions per minute," he builds it. But when I try to get an A. C. motor which does this, what is the result? It can't be found. Alternating current motors have certain speeds, determined by the frequency and the number of poles in the motor. You cannot change these relations. Summing up, in isolated plant work where long-distance transmissions do not occur, I would say that purchasers are deterred from buying A. C. motors, first, because of price; second, because of high speeds; and, third, because of inflexibility in application.

MR. E. A. SPERRY:—I am surprised to hear the last speaker sum up in his able manner on isolated plants without adding a fourth numeral, namely, the relation between direct current and storage. This, as we know, is often the point that determines the application, the point that determines which system has to be selected; and I have been rather surprised that so important a factor has been left out of the discussion up to the present time. And, Mr. President, if I may be permitted to digress at a considerable angle from the line the discussion has taken, while I have the floor I wish again to call attention to the really new apparatus that has been presented to us at this session, namely, that of Mr. Lincoln. I have seen the apparatus in operation somewhere at the Exposition, and I hope some one will tell us where, so that others may see it. It is certainly a most interesting device. I noticed particularly the directional factor. Not only does this tell us when we are not in step, but tells us which way out of step we are, which the ordinary apparatus, of course, does not do. This to me was of interest.

PRESIDENT STEINMETZ:—Gentlemen, before giving the floor to Mr. Dunn, I might be allowed to make one statement in reply to Mr. Mershon. In his discussion he said that the statement

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had been made before the INSTITUTE and elsewhere that the alternating current motor was good for nothing but the junk heap, and that this statement has gone unchallenged. Now, I really do not remember that such a statement has ever passed unchallenged, so far as the INSTITUTE is concerned, and I very much doubt that it has. I believe that is a mistake, Mr. Mershon probably referring to some other association. I shall be glad to hear from him, where and when this statement has been made. I now call upon Mr. Dunn.

MR. DUNN:—I had intended not to speak again, but Mr. Scott said one or two things to which I should like to reply. He mentioned that the induction motor had no field winding. It certainly has a field created by a winding, and I should like to ask which is better—a magnetic field which, though it may be created by a winding consisting of a number of turns of fine wire, stays still when once it is created, or a field created by a winding which has to borrow its magnetism from the circuit and restore it sixty times a second. I should prefer the still magnetism. He has said there is no commutator on the induction motor. Granted; but the induction motors, even to get them down to the price that they are now at, have to have such small air-gaps that their mechanical performance is questionable. The small air gaps cause jamming when they become filled with dust, and a slight wearing of the bearings lets the armature down on the fields, and even causes in some cases such unbalanced side pull as to bend the shafts when the motor is started.

Another trouble to which the direct motor current is not subject is vibration. The alternation of currents in the direct current motor is experienced only in the armature and not at all in the field, and it is of a very much lower frequency. The alternation of current in the induction motor causes a hum and often a vibration of the winding, which ends in rupturing and destroying the insulation. Now, with regard to maintenance, whether you use direct current motors or induction motors, you must have them regularly inspected. Any plant that puts up machinery without provision for regular inspection, gets into trouble sooner or later. I claim that the inspection required for direct current motors and the inspection required for induction motors is so nearly similar that the man who goes around to see that the oil is in the bearings; that the motors are clean; that the starting devices have not burned their tips, and that the belts are in order; that man can attend to an induction motor plant or a direct motor plant with very little difference in his time.

I did not mean that Mr. Scott said that induction motors were the best for all purposes, but such is the statement that many men selling induction motors make, and the statement that I have had to meet when I have been arguing the merits of direct current motors. I ventured to bring it forth in this discussion

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simply to give me a ground from which to talk. I would not risk my reputation by saying that direct current motors are the things to use everywhere; but what I do contend for, defend and believe in, is that for isolated plants, for work where you need controllability of speed, for work where you need large torques, there the direct current motor is greatly superior to the induction motor, and, withal, cheaper.

Mr. Scott went into the details of generator design, with regard to the size of the generator, but I think his point is not well taken, because there are facts, such as the difference in stiffness of field required in alternating generators and other details, that do not permit of any comparison being made, and where one cannot be made, following Mr. Mailloux's advice, we ought not to attempt it.

Taking up the double systems that Mr. Scott mentioned, that is, systems where they operate both alternating and direct currents in the same plant and out of the same generators, the reason they put in such double systems is because the alternating current system is not sufficient to do the work. I am of the opinion tha simplicity above all other things is requisite in engineering, and I do not see, where you want variable speed, heavy torques, constant speed, all kinds of service together, why you can't get those perfectly at lower cost and with a great increase in simplicity of plant by putting in one simple direct current system. This, of course, refers especially to isolated plants and factory equipments. If I were designing a plant which involved bringing power from a distance I should put in induction motors, the same as Mr. Scott.

THE PRESIDENT:—The object of our organization is to further the advance of electrical engineering, and most advance made has always been made as the result of criticism, that is, adverse criticism; and for that reason it is very desirable that we here should endeavor not only to show the advantages of the various systems of operation, but the disadvantages also; and when this discussion comes to your hands I hope you will carefully go over it and see, in the list of disadvantages of the continuous current machine, the commutator and brushes, etc, if you will find that there are still more to add to the list; and among the disadvantages of the alternating machine you will find power factors and small air-gaps, and you will add to that everything that you can still think of; and then in the future we can go over the matter and see how all these disadvantages can be remedied; because, while both types of apparatus are very perfect, we hope that in the future they will be still more so.

In connection with that, it would be desirable to hear from our European friends, and therefore I call on Mons. Boy de la Tour to give us a few words regarding European experience.

MR. HENRI BOY DE LA TOUR:—(Translation.) I believe that it is difficult to decide either for the direct current motor or for

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the polyphase non-synchronous (induction) motor. In my opinion there are numerous cases which call for the direct current, but there often exist installations where the use of the inductive motor has its advantages.

These motors have been criticised for their small air-gap and the large currents which they require in starting to produce a relatively low torque. But do not these motors present the material advantage of being, in comparison with the direct current motor, more simple, more robust, and of requiring, so to speak, no attention, and of being suitable to be put in the hands of almost any workman?

Mr. Steinmetz has said with reason that the synchronous motor could always be built so as to produce at starting the normal torque while absorbing only the normal current, but it is true also that it is possible, by means of special connections, to make a direct current motor give the normal starting torque with a current which is only from 65 to 70 per cent. of the normal running current.

The direct current motors have been very warmly defended here, and the idea has been admitted that they might, in the future, be preferred to the induction motors. One must not forget that inasmuch as nature does not produce anything but alternating currents, the laws of nature have, so to speak, been violated in the direct current motor. This thought makes me believe that the direct current machine can scarcely be the ideal definite machine, but that we find ourselves in a transitory period, and that the present induction motors, which are already excellent machines, will give place to a new alternating current motor, which will advantageously replace the two types at the present time before us. However, I repeat that in the present state of our science, the two systems both render us great services, for their different qualities enable them to complement each other happily to greatly facilitate the solution of problems which are oftentimes very difficult.

Mr. Henry W. Fisher:—From the experience of the manufacturer there may be something said on this point. I happen to be connected with the manufactories of the Standard Underground Cable Company, and in one factory we employ direct motors, and in the other factory induction, three-phase motors. Both factories have run successfully with the different types of motors but the difference is this, that every once in a while we have to take our direct current generator and our direct current motors and turn down the commutators, but in the case of the induction motors nothing whatsoever has had to be done. The induction motor generator does not have to be repaired, and the induction motor does not require any special attention as there is no commutator to be turned down. So that if I were putting up another factory I would certainly use the induction motors, because they certainly give less trouble than the direct current motors.

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MR. H. G. STOTT:—Mr. President, I would like to pour a little oil on the troubled waters and say that there is a connecting link between the alternating current and the direct current motor which we seem to have forgotten, and that is, the rotary converter. With that, the direct current man can look at the direct current side, and the alternating current man can look at the statics and the collector ring end.

Another point seems to have been overlooked, and that is as to whether we are receiving current or whether we are generating current locally for short distributions. These two points make a radical difference. If you are receiving current, undoubtedly the alternating current is the thing to use; but there are two ways of utilizing this, either with the static transformers and rotary converters and the use of direct current, or simply to put in static transformers and use.

Now, there is still a third way which in many cases is advisable, and that is to put in motor generators. You can put in a motor generator at almost any voltage, provided the unit is of large enough size, say 100 H. P. providing a 2200 or 4400-volt motor, either induction or synchronous. With the synchronous motors we have the advantage of running our power factor to any amount we wish. I think that we can all agree that there are certain cases where one motor is out of the question, and others where the other is out of the question. In a large plant being put in in New York, for instance, just now, the question of operating came in with regard to a coal-handling apparatus. Of course our engineers decided that the induction motor was the proper apparatus to handle that; but when it came to equipping the cars, all agreed in favor of the direct current motor, with just the same unanimity. There was no more question in the case of the one than in the other. So I think we can all agree to differ.

There is a point raised in one of the papers I think that is very important to central station men, which has not been taken up much, and that is the question of meters. In selling current it is unquestionably unfair to the central plant to sell current at the same rate per K. W. to men who only use the power during the peak of the load, for perhaps two hours, and throw this peak on top of the other load, as to the men who use the current for perhaps twelve hours a day, or even longer, and who use the current when it does not add on to the peak load. The peak load is the all-important factor in practically all plants. Now, I would like to hear from the representatives of the manufacturing companies as to what progress has been made in the designing of meters which would differentiate, as it were, between the two kinds of customers; in other words, a two-rate meter, or some other device, which would show the amount of current used between certain hours at the maximum, and also the amount of current used between certain hours of small load. I think that this is a very important point and that we could hear with a

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great deal of interest from the different representatives of the large manufacturing companies.

THE PRESIDENT:—I would like to call on Dr. Janisch of Germany to give us a few words concerning his experience on these topics.

MR. CHAS. JANISCH:—The question "Is the alternating or the direct current motor the better?" is a question which I would not like to answer without reservation. Both kinds of motors have their good qualities which enable them to operate positively and durably. Both kinds of motors have their disadvantages which make them more or less unsuitable for certain applications. For this reason, I would like to answer the question only after a careful consideration of the proposed working conditions, and would accordingly in one case give preference to the one, in the other case to the other motor. I am much pleased to coincide, in my view, with your President, and I hope with him that the present discussion will serve materially to improve either the one or the other of both kinds of motors to such extent that their preference for all applications may be incontestable, or that we may come across a new kind of motor which combines in itself all the good qualities of the two aforementioned kinds without possessing any of their disadvantages.

THE PRESIDENT:—I will call on Mr. Haskins, then, to answer any questions.

MR. HASKINS:—I think there has been but one question asked relating to my paper. In correcting the proof of my paper, I found that the compositors had substituted the word "motor" for "meter," all the way through, and it is possible that I ought to have left it there. I am hesitant whether to think that my paper has been in such full accord with your views as to call for no contradiction, or so completely in disaccord that time would not permit you to express your disapproval. I shall infer the first. Mr. Stott has asked me what progess has been made in the commercial development of a meter system contemplating a justly higher charge for energy furnished during the peak of the load than for energy furnished at other times. This problem translated into meter language, means the "two-rate meter." The General Electric Company has had a "two-rate meter" on the market for about three years. In its original form the meter had two dials. Motion from the rotating element of the meter was transmitted either to the right hand or left hand dial, according to the hour of the day, the throw-over being accomplished by a clutch controlled by a clock. It is possible with this meter to record the energy delivered during the peak period, be that what it may, on one dial, and to record on the second dial all energy consumed at other than the peak period. The clock is capable of being set to throw over at any desired time from high to low and from low to high rate. I do not think it is appropriate that I should enter into a discussion of the two-rate system

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here. It is more of a commercial than a technical topic. The double-dial form of meter, which was our first two-rate device, involved the reading of two dials, and practically the preparation of two bills—somewhat of a burden. It has been superseded by a second form of two-rate meter which has but a single dial, the reduction of rate during the "valley period" of the load, being accomplished by an actual reduction of speed of the rotating element. This change is accomplished by cutting in and out resistance in series with the armature. This provides a two-rate meter which may be any desired percentage slow during the "valley period," and at the same time involves the reading of but a single dial. The discount or reduction of rate during the "valley period" is taken care of by the reduction of speed rate in the rotating element during those hours. The change in resistance is accomplished by a clock mechanism similar to that originally used with the two-dial meter. This meter is undoubtedly preferable for two-rate purposes, and it is my candid personal belief that some day it will come into very wide use.

MR. W. HAND BROWNE:—I will not venture, Mr. President, into the discussion of the relative merits of induction and direct current motors. The question of charging for the wattless current I would also prefer to leave to the operating engineers. It was stated that a great deal of trouble had been experienced in the use of older and poorer induction motors. Would not a power factor indicator at once condemn such a motor?

[Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT, BY GANO S. DUNN, see page 864.]

In the discussion of the relative performance of direct current and induction motors into which channel the discussion of Mr. Caryl D. Haskins' paper on meters at the Buffalo convention, turned, I referred to certain tests I had made and gave extracts from them, and upon the suggestion of one of the speakers I now submit these tests as a part of the discussion communicated after adjournment.

The tests are plotted in three sets of curves, all on one sheet shown herewith.

The first set gives the speed characteristics of the direct current shunt motor, direct current compound motor and alternating current induction motor.

The second set gives the efficiencies, and the third gives the running currents for these same motors. The three sets are distinguished by the character of their lining, which is explained upon the sheet. All of the curves are plotted with torque for the independent variable.

To secure comparative results, the scales have been written in percentages of the full load values of each quantity involved.

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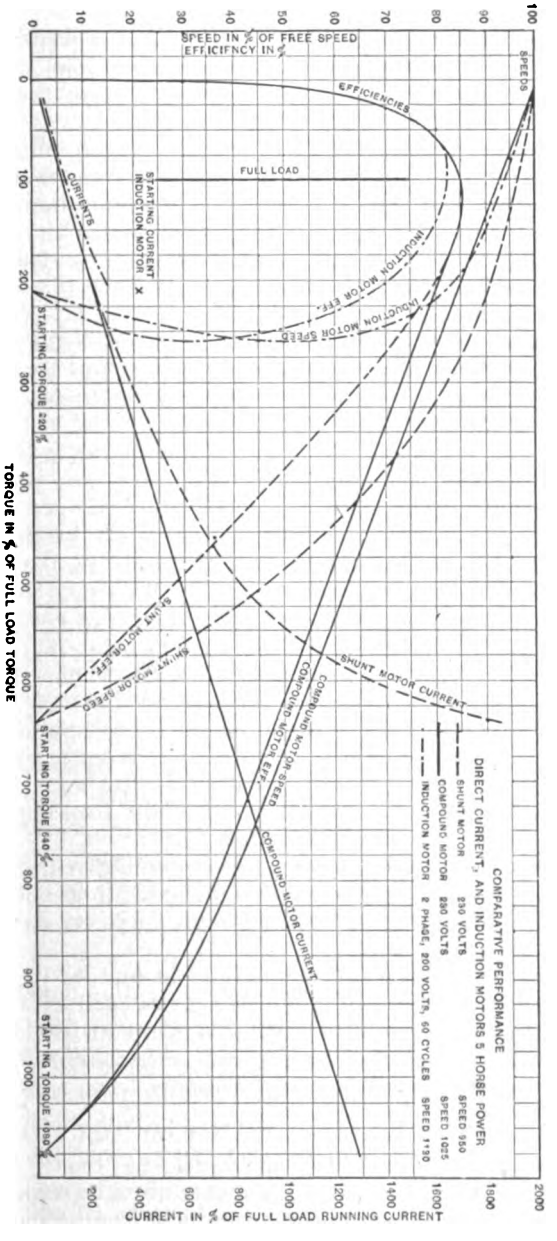
SPEED IN % OF FREE SPEED
EFFICIENCY IN %
EFFICIENCIES
SPEEDS
FULL LOAD
CURRENTS
STARTING CURRENT INDUCTION MOTOR
INDUCTION MOTOR EFF.
INDUCTION MOTOR SPEED
STARTING TORQUE 220 %
SHUNT MOTOR EFF.
SHUNT MOTOR SPEED
SHUNT MOTOR CURRENT
COMPOUND MOTOR EFF.
COMPOUND MOTOR SPEED
COMPOUND MOTOR CURRENT
STARTING TORQUE 640 %
STARTING TORQUE 1980 %
TORQUE IN % OF FULL LOAD TORQUE
CURRENT IN % OF FULL LOAD RUNNING CURRENT
COMPARATIVE PERFORMANCE
DIRECT CURRENT, AND INDUCTION MOTORS 9 HORSE POWER
SHUNT MOTOR 230 VOLTS SPEED 950
COMPOUND MOTOR 230 VOLTS SPEED 1025
INDUCTION MOTOR 2 PHASE, 200 VOLTS, 60 CYCLES SPEED 1150

The data from which the curves for the induction motors were made, were taken from the publications of one of the prominent companies building such machines. The data from which the

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curves for the direct current motors were made, were taken from tests made under my personal supervision, especially for this comparison, and were from ordinary commercial machines of standard commercial rating, drawn directly from the storehouse and unmodified in any particular.

The current curves show that for full load the induction motor requires about 10 per cent. more running current than the direct current motor, and that this excess of current increases as the motors become overloaded. They also show that the starting current for the induction motor at its maximum starting torque is nearly twice as great as the starting current for the same torque in the direct current motor.

The curves of efficiency show that at partial loads there is little difference between any of the motors, but at full load the induction motor is about 3 per cent. lower than its direct current competitors and at overload greatly lower.

The speed curves originating in the upper left hand corner, show that in regulation between free speed and full load the direct current shunt motor falls off about 4½ per cent., the induction motor about 6 per cent. and the direct current compound motor about 7½ per cent., and that the induction motor breaks down and stalls at a maximum torque of 2.7 times normal, while the direct current shunt motor continues until it exerts a torque of 6.4 times normal and the direct current compound motor continues until it exerts a torque of 10.8 times normal before it stalls. The speed curves also show that at the breakdown point of the induction motor the direct current shunt motor has fallen off in speed only 13½ per cent. and that at a torque of about 80 per cent. above normal the regulation of the compound motor and the induction motor are about equal and that beyond this the compound motor is greatly superior.

A series wound direct current motor would give greater torques than the compound wound, but as it would not be comparable with the induction motor in speed regulation, its data were not included.

Sparking occurred in the direct current motors in the middle region of their speed curves, but it was not such as would injure the commutator unless the overloads were maintained; and at the severest overloads the sparking almost disappeared, on account of the low speeds that accompanied them.

[Communicated After Adjournment by Mr. Carl Hering. See page 325.]

Mr. Mailloux's observation, which differed from mine, does not affect the real point at issue, which is, whether it *can* be done, and not whether it *was* done, under the particular conditions of load, grade, motorman, etc., under which he made his observation. If it can be done once it can be done again, although it may not always be done, especially when power is as cheap as it is on that line.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22nd, 1901, President Steinmetz in the Chair.

PERFORMANCE OF AN ARTIFICIAL FORTY-MILE TRANSMISSION LINE.

BY WILLIAM S. ALDRICH AND GEORGE W. REDFIELD.

The artificial duplication and test of a 40-mile transmission line was carried out as far as facilities would permit in the Electrical Engineering Laboratory of the University of Illinois during the Spring semester of 1901. The combinations selected were such as would cover a wide range of conditions in practice. The results obtained represent closely those that might be expected under commercial conditions of a similar line. The characteristics of performance illustrate the evil effects of shifting phase displacement as the chief cause of poor regulation.

General Considerations and Requirements.—The kind of service and requirements at the receiver end of the line involve a consideration of the kind of load, such as synchronous motors or converters, induction motors, arc and incandescent lights, or any combination of these. In the design of the line the prime factors are load, distance, voltage, frequency and allowable drop and loss. There is usually allowed a maximum drop for the given conditions. Such an allowance depends upon the kind of service employed, the character of the load and the inherent properties of the line, such as ohmic resistance, self-inductance, capacity, frequency, line current and its phase displacement.

The character and variation of receiver loads also largely influence the line regulation, losses and efficiency. The voltage, cost of conductors, cost of construction and maintenance and insulation to prevent leakage deserve some share of consideration.

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The energy or I^2R loss in the line, in per cent. of the full load power delivered to the line, usually varies between 5 and 10%, in the best modern transmission installations. The charging current and receiver wattless components of current, if any, will indirectly vary this I^2R loss according to whether they are neutralized or not.

Effect of Reactive Loads Upon Line Efficiency.—The effects of reactive loads upon the performance of the generator are well understood and have been set forth in numerous experiments. The effect of such loads upon the transmission is to increase the current for the same energy transmitted over that required when

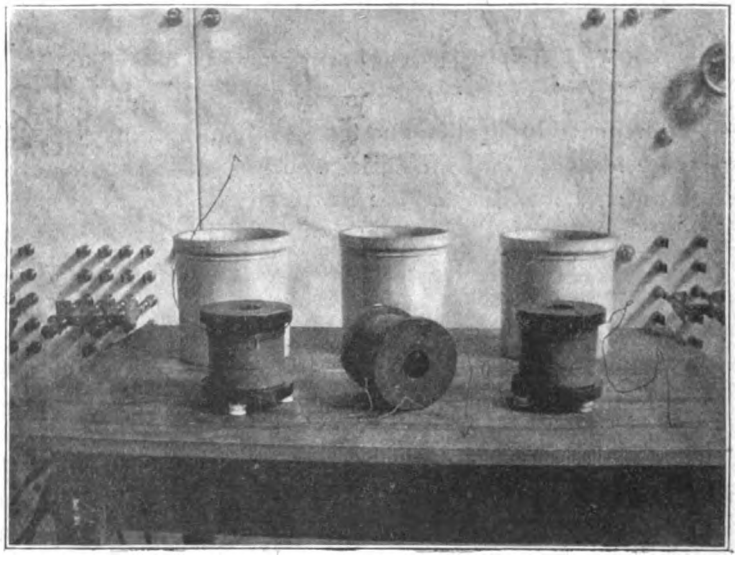

FIG. 1.—Coils for Artificial Reactances.

the current in the line is in phase with its impressed E. M. F., the line loss increasing, as the square of the current will be much increased with increase of phase displacement. From this consideration alone it would appear that the line current should be in phase with its E. M. F. for most efficient performance. Considering, however, the voltage and drop for a given amount of power delivered, it is to be noted that conditions may arise in practice in which an inductive line may transmit energy at a higher efficiency than a non-inductive one.

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Conditions Assumed.—It is desired to transmit, by three-phase system, with step-up and step-down transformation, from 1 to 8 K. W., 40.75 miles, at 2,300 volts and 64 cycles, with a transmission efficiency, between generator terminals and receiver secondary terminals, of not less than 80%, at full and practically non-inductive load on the receiver secondary circuit. The size and frequency were necessarily determined by the polyphase generator available.

No. 4 (B. & S. gauge) copper wire was selected, giving a line loss per phase of 0.215 K. W., or about 8%, on a basis of 2.66 K. W. output per phase from receiver secondary terminals, under normal voltage and non-inductive load. The line constants chosen are suited to a distance apart of the wires of 18″ at the vertices of an equilateral triangle.

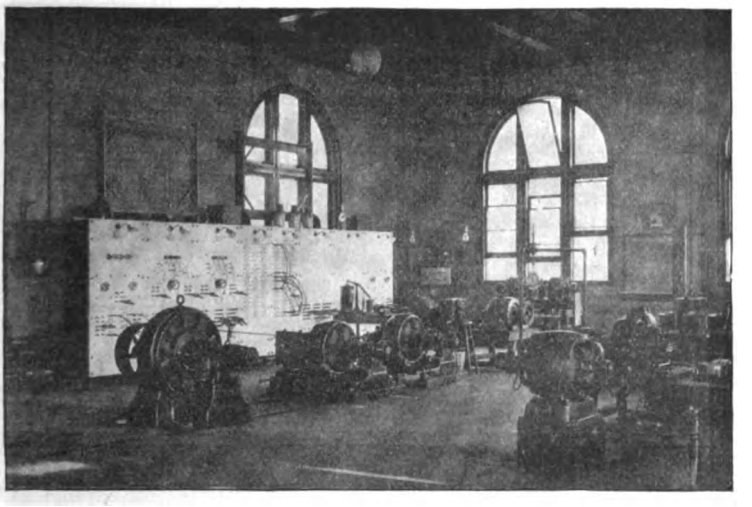

FIG. 2.—Arrangement of Artificial Line Above Switchboard.

Self-Inductance and Inductive Reactance.—The artificial inductive reactance provided for each wire of the three-phase line was an air-core coil, wound and adjusted to the proper self-inductance of this line wire under the conditions assumed. Maxwell's bridge method[1] was used in standardizing these three inductances. The accuracy of the standard inductance and resistances used and the sensitiveness of the galvanometer warranted an accuracy to within one-fifth of 1%. Air-core coils were selected to insure

1. Maxwell's "Electricity and Magnetism," vol. ii., p. 367.

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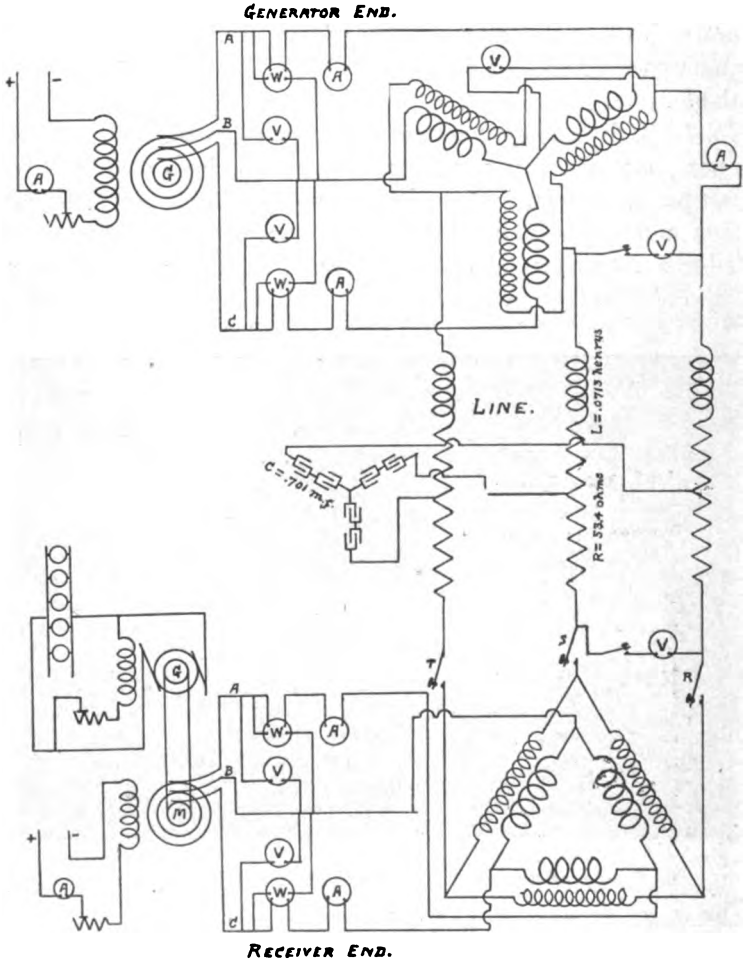
that such equivalent inductance of the artificial line (and therefore its reactance at constant frequency) would remain constant throughout all variations of line current. These reactance coils, Fig. 1, were each immersed in earthenware jars filled with a high



CONNECTIONS FOR TESTS OF 40 MILE ARTIFICIAL TRANSMISSION LINE.

FIG. 3.

grade of transformer oil and always used in this condition. While in use they attained a temperature of approximately 70° C., and remained practically at this temperature during the experiment. The resistance of each coil at this temperature was 9.0 ohms.

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Ohmic Resistance.—The total ohmic resistance of each line wire for the given conditions should be 53.4 ohms. To supply the remaining 44.4 ohms for each line wire, three non-inductive resistances were constructed by winding No. 17 (B. & S. gauge) German silver wire non-inductively upon frames, as shown above the switchboard, Fig. 2. These resistances were each adjusted by an accurate Wheatstone bridge to the value of 44.4 ohms, at about 85° F., the temperature of the room.

Capacity and Capacity Reactance.—The artificial capacity of the three-phase line was composed of six commercial electrostatic condensers, two condensers each being connected in series and thence connected in star between the three line wires. These condensers were arranged so that the capacity between each of the line wires and the neutral was 0.701 micro-farads. The outer terminals of the star-connected condensers were respectively connected to the middle points of the non-inductive resistances of each line wire, Fig. 3. Such an arrangement was equivalent to concentrating all of the capacity of the 40.75-mile transmission line midway between the generator and receiver ends.

TABLE I.

DATA OF ARTIFICIAL TRANSMISSION LINE.

Length of transmission	40.75 miles
Diameter of conductors, No. 4 B. & S.	0.204 inches
Area of conductors	41,742 cir. mils.
Resistance per mile at 75° F.	1.31 ohms
Frequency, cycles per second	64

CONSTANTS OF THE LINE COMPUTED FROM THE ABOVE DATA.

Inductance per mile of wire or ½ mile of transmission	0.001750 henrys
Inductive reactance per mile of wire, 64 p. p. s.	0.703 ohms
Impedance per mile of wire, 64 p. p. s.	1.487 ohms
Impedance factor of line (impedance divided by resistance)	1.134
Resistance of 40.75-mile transmission line (or 81.50 miles of line wire)	106.8 ohms
Inductance of 40.75-mile transmission line (or 81.50 miles of line wire)	0.1426 henrys
Inductive reactance of 40.75-mile transmission line, 64 p. p. s.	57.3 ohms
Impedance of 40.75-mile transmission line, 64 p. p. s.	121.2 ohms
Capacity of each wire to neutral per mile of transmission line	0 01722 m. f.
Capacity reactance between two wires per mile of transmission at 64 p. p. s.	1,449,300 ohms

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Capacity of 40.75-mile transmission line considered as two parallel cylinders	0.701 m. f.
Capacity reactance between two wires of 40.75-mile transmission line	355.300 ohms
Charging current per phase of 40 75-mile transmission, 64 p. p. s. and 2,300 volts	0.374 amperes
Total apparent energy to charge line, 64 p. p. s. and 2,300 volts	1.49 K. W.
Total true energy to charge line, 64 p. p. s. and 2,300 volts, or total I^2R due to charging current	0.011 K. W.
Current per phase to transmit 8 K. W. at 2,300 volts and unity power factor	2.01 amperes

TABLE II.

DATA OF THE ARTIFICIAL SUBSTITUTES FOR LINE CONSTANTS.

Size of wire of reactance coil for each line wire	No. 18 B. & S. gauge
Inside diameter of each reactance coil	1.87 inches
Outside diameter of each reactance coil	4.0 inches
Length of each reactance coil	14.25 inches
Approximate number of turns on each reactance coil	1,420 turns
Inductance of each reactance coil	0.0713 henrys
Ohmic resistance of each reactance coil, 70° C	9.0 ohms
Resistance of non-inductive portion of each line wire	44.4 ohms
Total ohmic resistance of each artificial line	53.4 ohms
Equivalent artificial capacity per phase of each line wire to neutral	0.701 m. f.

Connections Used in Operation.—The reactance coils were placed at the receiver end, all of the line reactance being assumed as concentrated at that point. In series with each of these reactance coils was placed one of the non-inductive resistances, with its respective condensers.

The connections of apparatus and instruments for the various experiments are shown in Fig. 3. In the experiments for charging current and resonant rise, the switches R, S and T were open.

Description of the Generator.—Three-phase current was generated from a machine made by the Westinghouse Electric and Manufacturing Company, constructed for single and polyphase work, as generator, synchronous motor or converter. The armature has a distributed winding, and was here tapped off as a three-phase delta combination.

DIMENSIONS AND MEASUREMENTS OF GENERATOR.

Type	Polyphase converter
Serial number	135,751
Capacity	10 kilowatts
Number of poles	4
R. P. M.	1,920

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Frequency	64 cycles
Normal volts (three phase)	410
Full-load current per branch (three-phase)	14 amperes
Resistance of field (hot)	685 ohms
Resistance of armature per phase (hot)	0.92 ohms

External Characteristics of Generator.—External characteristics were taken of this machine under various reactive loads with lagging and leading phase displacement[1]. The results are shown

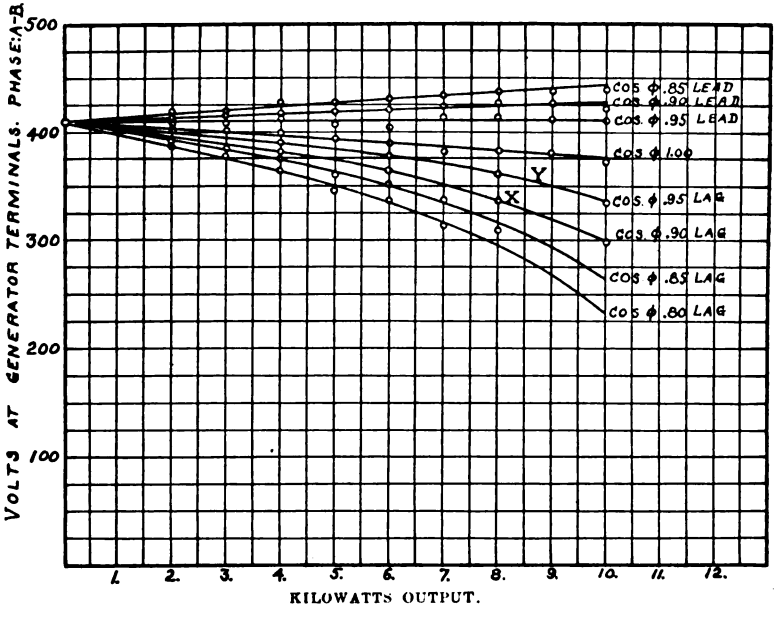

FIG. 4. External characteristics of Westinghouse 10 K.W. Alternator as three-phase Generator, showing the effect of Variable Reactive Loads on Regulation.

in Fig. 4. In obtaining each of these curves the true power was measured by the two-wattmeter method. The power factor of the external circuit was kept constant throughout the whole range of load by maintaining constant the ratio of the two-wattmeter readings.[2]

1 "The Regulation of Alternators under Variable Reactive Loads." Geo. W. Redfield, *Technograph*, University of Illinois No. 15, p. 95, 1901.

2 "Power Factor Measurements." B. Frankenfield. *Electrical World and Engineer*, vol. 35; p. 178. Feb. 3, 1900.

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Charging Current of the Artificial Line.—The receiver end was open-circuited and the charging current measured as on a three-phase line. One of the line wires at the generator end was

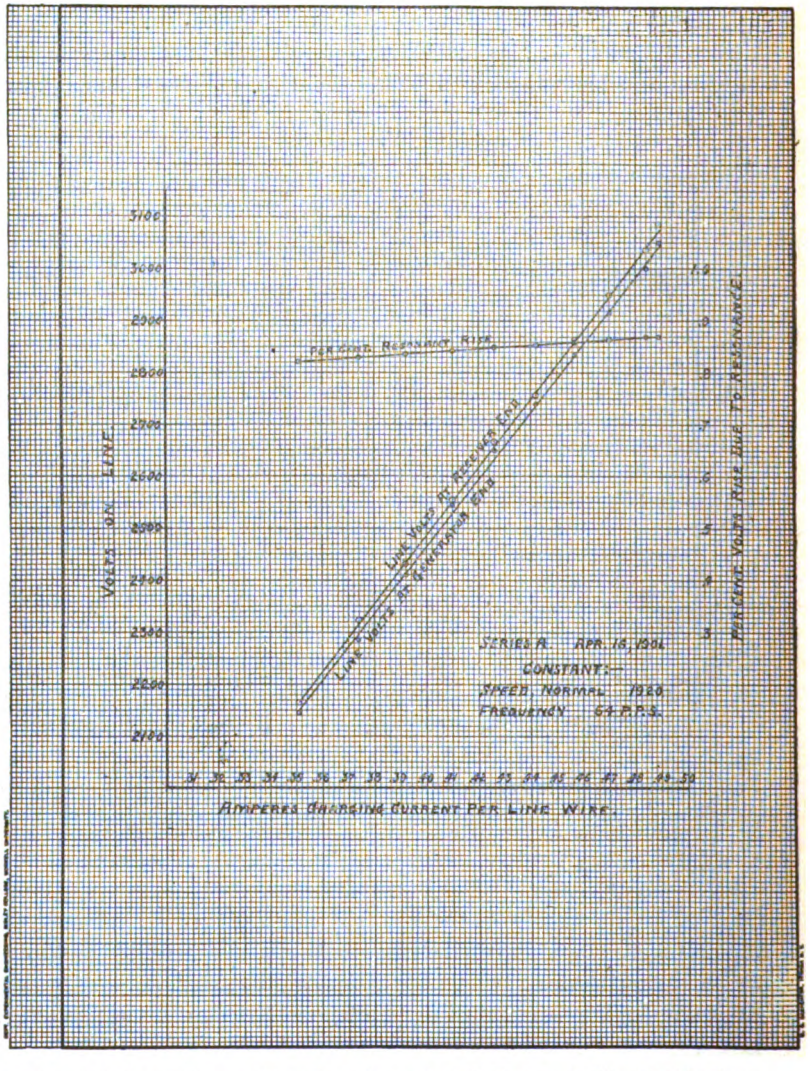

FIG. 5.—Relation Between Charging Current and Resonant Rise for Various Voltages at Generator End.

disconnected and the charging current measured with the same voltage and frequency applied to the line as before. In the case of the three-phase line the total charging current was $2/\sqrt{3}$ that of the charging current of the single-phase line.

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Resonant Rise—An experiment was made to determine the rise of voltage at the receiver end primarily due to resonance. The line at the receiver end was opened and a Weston

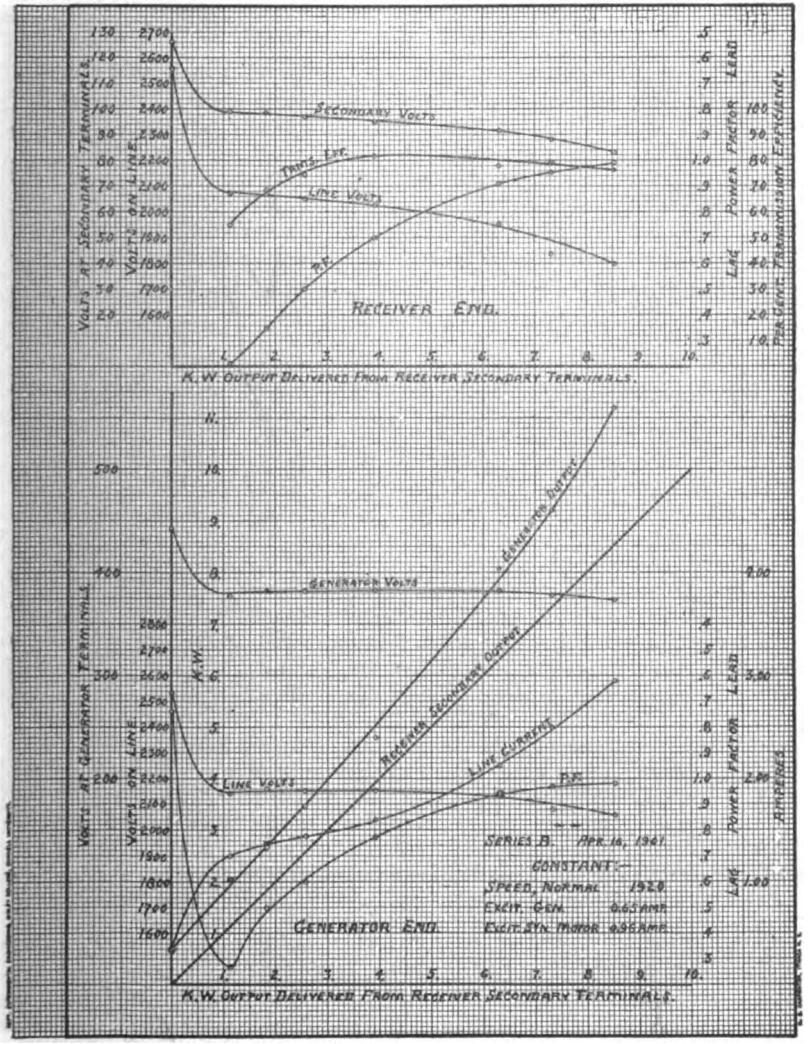

Fig. 6.—Performance of Transmission at Variable Load with Under-Excited Synchronous Motor.

voltmeter, with suitable multiplier, was then placed across the terminal of one of the phases. Fig. 5 shows the results of this experiment, giving the relation between charging cur-

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rent and resonant rise for various voltages at generator end. During the interval when the charging current was measured the voltmeter was not in circuit, and hence there was no current taken off the line at the receiver end.

Let e = percentage rise of potential due to resonance.[1]

C = total capacity of line, in farads.

L = inductance in henrys, of total length of one circuit.

$\omega = 2\pi n$, where n is the frequency or p.p.s.

$$\text{Then, } e = \frac{C\,\omega\,L\,\omega\,100}{2}.$$

The quantities C and L are proportional to the length of line and therefore the percentage rise in potential varies practically as the square of the length of the line and the square of the frequency.

Substituting in this formula the values for the 40.75-mile line, we have,

$$e = \frac{10^{-6}\times 0.701\times 401.5\times(0.0713\times 2)\times 401.5\times 100}{2} = 0.816$$

this being the calculated per cent. rise due to resonance for this line. By a glance at Fig. 5, it will be noticed that the observed values for the per cent. resonant rise agree very closely with the above computed value. It also shows that this per cent. resonant rise is practically independent of the voltage applied to the line.

All power factor values of the three-phase circuit were determined from two-wattmeter measurements by use of the well-known curve of ratios of wattmeter readings in connection with the cosine curves for balanced three-phase system.[2]

Power Factor at Generator End on Open Receiver Secondary. —When the receiver secondary circuit is open it will be noticed in all of the curves of performance that the power factor at the generator end is leading. The reason for this will be evident upon considering a series of readings by the two-wattmeter method, one or the other wattmeter always having the larger

1. "The Use of Aluminium Line Wire, and Some Constants for Transmission Lines," by F. A. C. Perrine and F. G. Baum, TRANSACTIONS, vol. xvii., p. 345.

2 Ibid. Frankenfield.

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reading according to whether the resultant power factor of the three-phase line is leading or lagging. The current in the line under these given conditions is known to be leading because the charging current is in excess of the no-load current required by the transformers. Further evidence that the power factor at the generator end is leading is shown by the line voltage at the receiver end being higher than the line voltage at the generator end, and such a condition could not be possible, owing to the inductance of the line unless there was a leading current in the line. For no-load on the secondary, at the receiver end, similar conditions are obtained in all subsequent tests; hence, the resulting leading power factor of the three-phase transmission is the same in all cases of open receiver secondary.

Description of the Synchronous Motor.—The transmitted power was absorbed at the receiver end by a machine made by the General Electric Company, constructed for single and polyphase work, as a generator, synchronous motor or converter. The armature has a distributed winding and and was used as a three-phase machine.

DESCRIPTION OF SYNCHRONOUS MOTOR.

Type	Synchronous Machine.
Capacity	7½ K.W.
No. of poles	4.
R. P. M.	1920.
Frequency	64 cycles
Normal voltage (three phase)	110
Full load current per branch (three-phase)	40 amp.

Performance of Transmission at Variable Load with Under-Excited Synchronous Motor.—The curves of performance, Fig. 6, show that as soon as the synchronous motor is thrown on, as a lightly loaded receiver, at constant excitation of 0.96 amperes, taking about 1.1 K.W., the phase displacement at the generator end immediately changes from lead to lag. The line current rises quite rapidly and the high-tension and low-tension pressures at each end drop considerably, due to the presence of lagging currents in the line and generator circuit. Under such conditions the regulation of the generator is greatly impaired, as shown in Fig. 4. The under-excited synchronous motor is similar in its effects upon the transmission system to an induction motor, producing lagging phase displacement materially affecting the regulation of the system. As the load in-

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creases, the line drop at receiver end falls off gradually, while the current comes rapidly into phase with the impressed E.M.F., reaching unity power factor at a trifle over full load. This effect

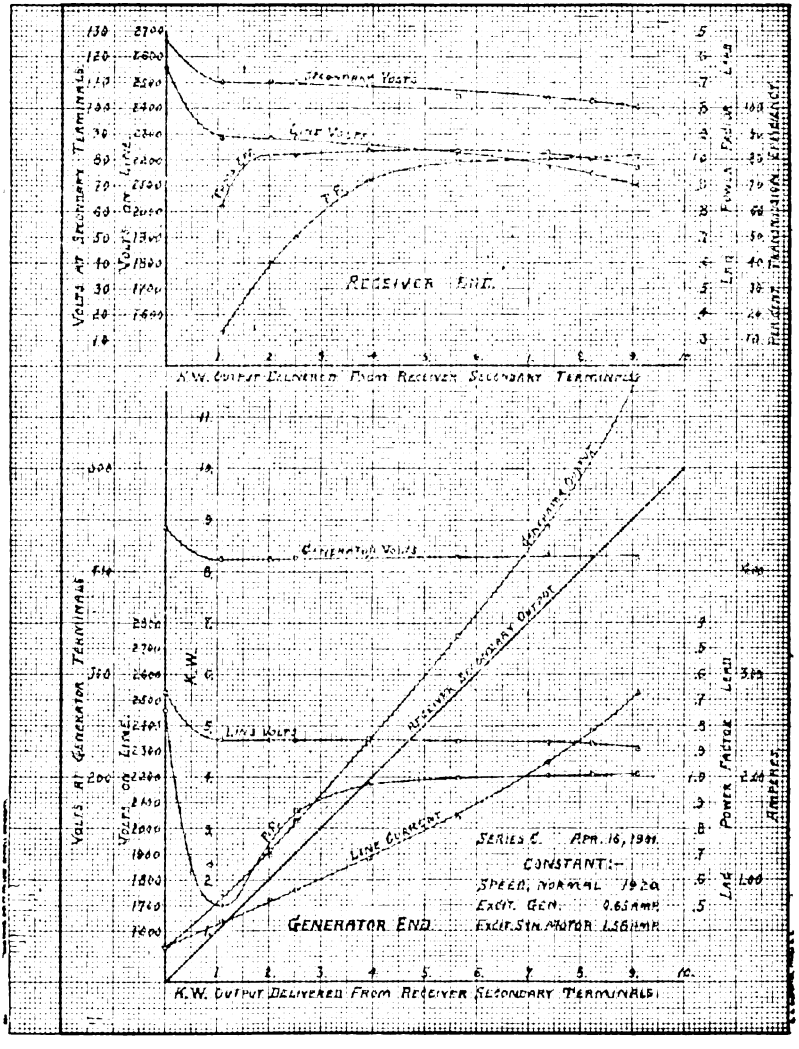

FIG. 7.—Performance with Normally-Excited Synchronous Motor.

partially compensates for the increased drop due to heavier loads and therefore has a tendency to keep the voltages up. The phase displacement at the receiver end controls the phase relations of

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these E.M.F.'s. The line current is exceptionally high under light loads, because under such conditions the receiver power factor is very low.

$$\text{Transmission efficiency} = \frac{\text{Output of receiver secondary}}{\text{Input from generator terminals}}$$

The efficiency in this case reaches a maximum value of 82%, at about half load, and has a maintained value of 80% and over from one-third to two-third load.

Performance with Normally Excited Synchronous Motor.—The characteristics under this condition, are shown in Fig. 7. The constant excitation of the synchronous motor was 1.58 amperes, the excitation for its operating at practically unity power factor above half load. The resulting power factors are much improved at the generator and receiver ends under light loads. As the load increases, each of these power factors increase more rapidly than in the preceding case, and at full load they reach unity while beyond this point they are a trifle leading. The line drop is not so marked, resulting in better inherent regulation of the system.

The pressure at the generator end remains practically constant after the synchronous motor is thrown on the line. The line current rises gradually, improving the line efficiency by reducing the phase displacement, also improving the transformer efficiencies. Owing to this the transmission efficiency rises quickly and maintains a high value of 82% and over from one-fifth to full load. This bears out the earlier statements of this paper that best results are to be obtained in such a transmission system when the resulting phase displacement is a minimum.

PERFORMANCE WITH OVER-EXCITED SYNCHRONOUS MOTOR LOAD.

The curves of performance under this condition are shown in Fig. 8. The constant excitation of the synchronous motor was 2.58 amperes. The pressure at the generator end does not drop at all when the over-excited synchronous motor is thrown on, having a tendency to rise, due to the phase displacement of its external circuit remaining leading at all loads. This is equivalent, in its effects upon the generator, to over-compounding, producing the so called "boosting" effect, as shown in Fig. 4, for an equivalent power factor of about 0.90 leading. The secondary

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pressure regulation at the receiver end is better than in any previous case, being exceptionally good due to a leading phase displacement which increases with the heavier loads. This has a

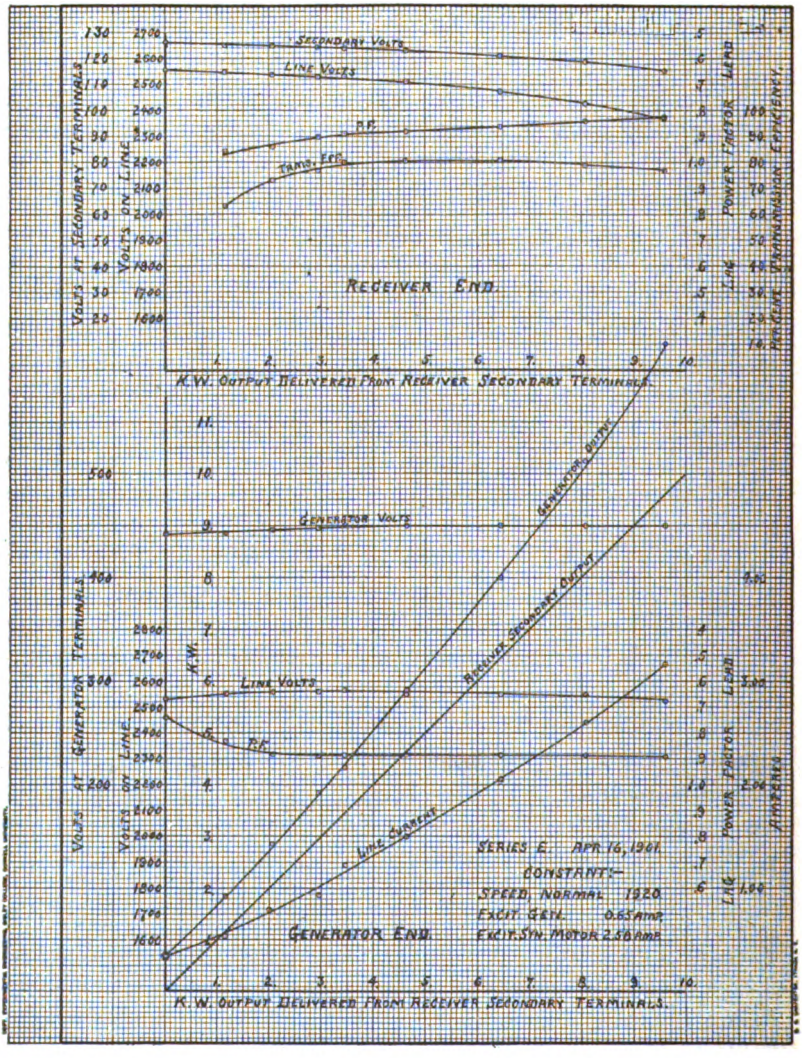

Fig. 8.—Performance with Over-Excited Synchronous Motor Load.

compensating effect upon the secondary receiver voltage which will be noted later.

The transmission efficiency is 80% and over from half to full load. In this case the efficiencies of the transformers are evidently re

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duced at their respective loads by the increased core losses under the higher impressed voltages. Their I^2R losses are also increased for the same respective loads owing to the increasing phase displacement.

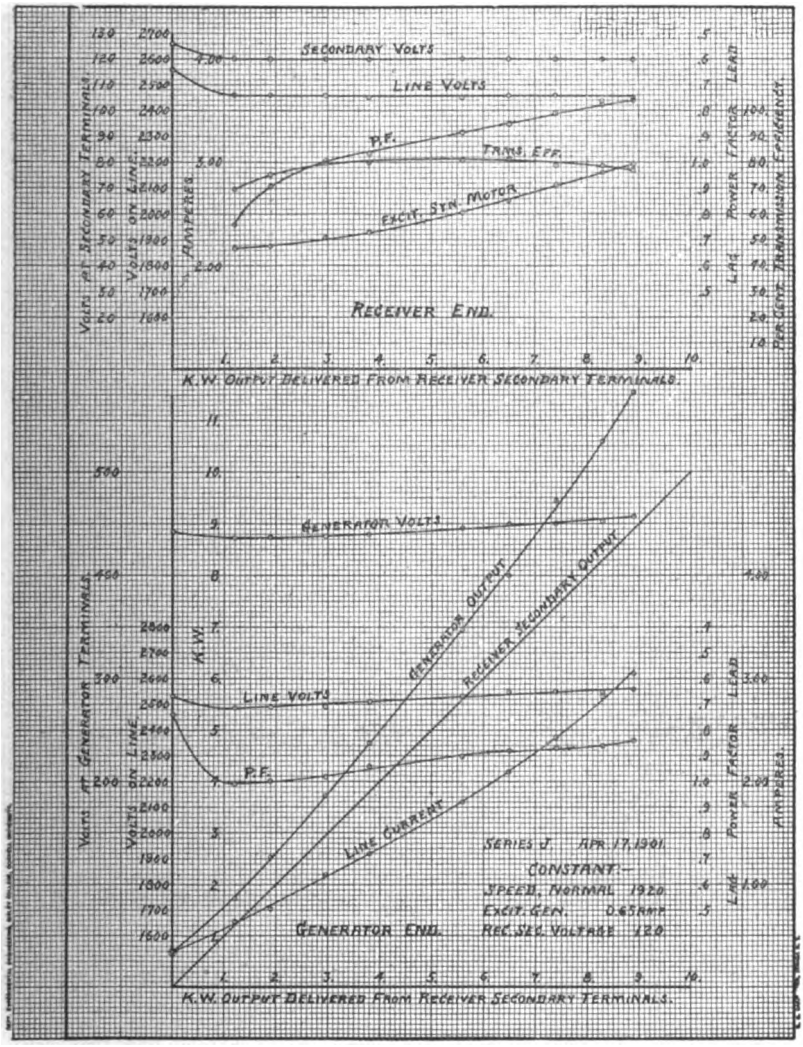

FIG. 9.—Performance with Constant Receiver Secondary Voltage, 120 Volts, and Variable Excitation of Synchronous Motor.

Constant Receiver Secondary Voltage and Variable Excitation of Synchronous Motor.—Fig. 9 illustrates the performance where a constant pressure of 120 volts was maintained at the

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receiver secondary terminals while the excitation was correspondingly increased with the load. There is increasing leading phase displacement after the small loads are passed. The transmis-

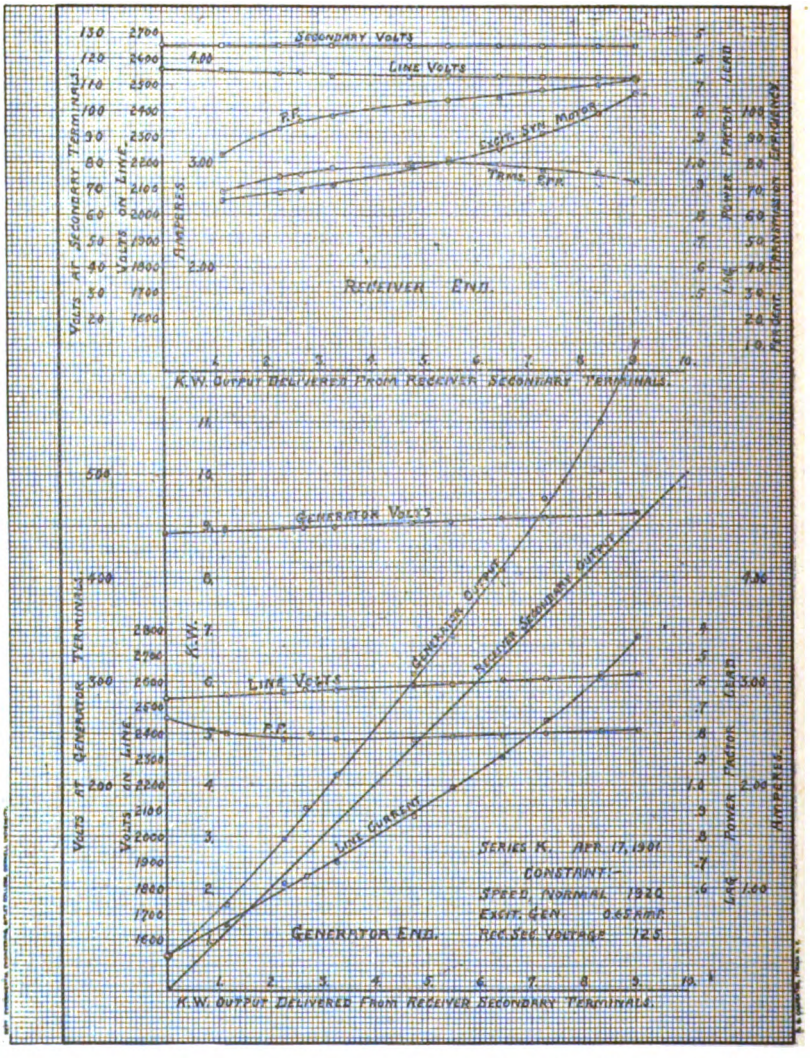

FIG. 10.—Performance with Constant Receiver Secondary Voltage, 125 Volts, and Variable Excitation of Synchronous Motor.

sion efficiency is at and above 80% from one-third to full load. Under similar conditions the receiver secondary voltage was maintained at 125, the no-load pressure, and the results are plotted in Fig. 10. The phase displacement at each end is de-

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cidedly leading. Therefore the line current is materially raised, increasing the I^2R losses. Under this condition the transformers were operated at still higher pressures, correspondingly decreasing the efficiency of transmission.

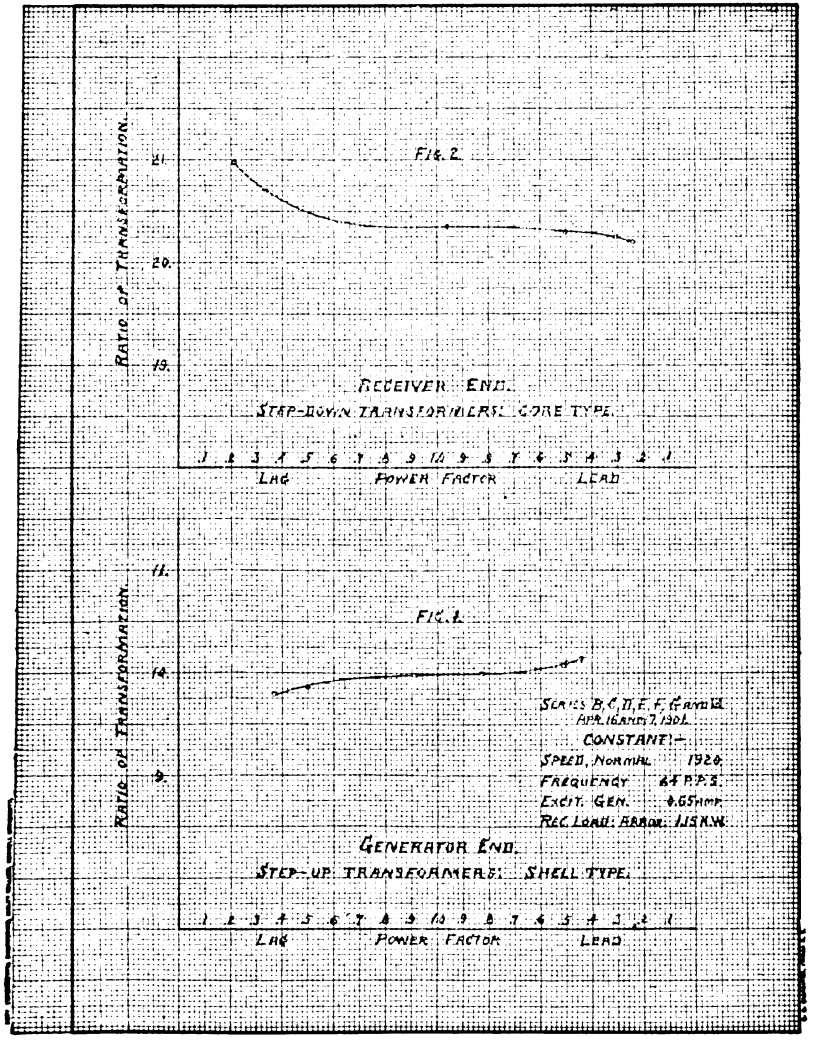

FIG. 11.—Variation of the Transformer Ratios as Function of the Phase Displacement.

Effect on Generator Voltage by Increasing Synchronous Motor Excitation.—Under the leading phase displacement of the last

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two experiments the pressures at the generator show the characteristic increase earlier noted in Fig. 4.

The leading wattless components of current are comparatively large, and therefore have an appreciable influence upon the performance and regulation of the generator.

Regulation of Transformers Under Variable Phase Displacement.—An examination of the transformer ratios as determined by the voltage curves at the generator and receiver ends of the preceding curves of performance, will show that for the small loads especially, the ratio of transformation at each end of the line varies greatly with the phase displacement. This variation of transformer ratios is a function of the phase displacement depending upon whether it is lagging or leading.

Fig. 11 shows the plotted values of these variable transformer ratios, as a function of the power factor for the step-up and step-down transformers respectively. The load was practically constant, at 1.15 K.W., for all of these determinations. The variation in the ratio of the step-down transformers is opposite to that of the step-up transformers.

The following is the general principle for either step-up or step-down transformers, respecting the variation in transformer ratios with variable phase displacement:

The output voltage increases as the lagging phase displacement decreases, which voltage continues to increase as the displacement passes through unity and becomes more and more leading.

This variation of transformation ratio will become apparent upon a consideration of the effect of variable phase displacement upon the resultant flux. In any given case this flux is smaller with a lagging phase displacement than with no displacement, and, therefore increases as the displacement becomes more and more leading.

Therefore, with a given primary impressed E.M F. the secondary E.M.F. will be smaller with a lagging and larger with a leading load, than with a simple non-inductive load. Furthermore, it is to be seen that a difference of phase existing in the secondary circuit of a transformer reappears in the primary circuit somewhat decreased if leading, and slightly increased if lagging.

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Precautions to be Taken with Unloaded Transmission Lines.

Judging from the results of the earlier sets of these experiments it should not be permitted to throw the generator onto an unloaded transmission line where the per cent. resonant rise may be comparatively large. If this should occur it may produce a marked resonant rise in pressure at the receiver end, and moreover increase the ratio of the step-up transformers. It is therefore advisable always to have induction motors or similar inductive reactance connected in the circuit. Furthermore, in designing a transmission line care should be taken to keep very low the ratio of the charging current to the full load power current, so as not to necessitate increasing the size of generating units to supply this charging current.

Transmission Efficiency.—The tendency to higher efficiency by increase of the impressed E M.F., due to any so-called "boosting" throws the current out of phase with its E.M.F. It is evident that when high transmission efficiency is desired it is necessary to keep down the wattless components of current to whatever cause they may be due, quite as much on account of the impairment of transformer efficiency as in the general operation of the system. The three transformers used at each end of the line were of 3 K.W. capacity, of well-known modern types; Fort Wayne for the step-up, and Packard, for the step-down transformers. In almost all instances in these experiments they were operated at somewhat higher voltages than intended. Their I^2R losses were necessarily increased by the extreme range of reactive loads.

Voltage Regulation.—The results throughout are given for one phase (A–B) of the three-phase system, which was always balanced. There was comparatively little "hunting" of the synchronous motor under any of the conditions of operation. The transformers had a drop of 3% between no-load and full non-inductive load when operated at their normal voltage. There was also a drop of about 2% in the speed of the alternator between no-load and full-load, due to the increased slip of the induction motor used as a prime mover. After taking these factors into consideration regarding the regulation of the several parts of the system, it is evident that the performance of the transmission system was satisfactory.

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Wave Forms from the Experimental Transmission System.[1] The instrument used in taking these wave forms was a modification of the Blondel oscillograph. To a small reflecting mirror was attached a very soft Norway iron needle, with a natural period of about one thousandth of a second. This was suspended vertically by a very fine silk fiber in line of prolongation of horizontal axis of an air-core solenoid of sixty turns of No. 20 (B. & S.) soft single cotton-covered magnet wire. The directive force of the needle was supplied by a pair of permanent steel magnets of horse-shoe form, producing practically a constant field. When an alternating current was passed through the solenoid it produced simultaneous deflection of the needle in frequency, direction and amount proportional to that of the current flowing.

By suitably arranged lenses a beam of light from an arc lamp will be reflected by the mirror upon highly sensitized paper mounted on a rapidly-revolving drum.

The photographic records of the wave forms are necessarily small, from one-half to one inch in amplitude. They were enlarged by throwing onto a screen by a projection lantern and then retraced by hand. Similar recording arrangements have been used with curve tracers. These are necessarily slow and tedious, requiring about half an hour for a complete record of the wave form. The record, therefore, is really a kind of composite photograph, as the wave form meanwhile may have undergone almost an infinite variety of changes. In the modification of the oscillograph as here used the deflections of the needle follow very closely and faithfully any variation in the alternating current, and a record of the wave form is obtained in about one-sixtieth of a second.

Figs. 12 and 13 illustrate the generator and receiver wave forms under typical conditions. Series X is an E. M. F. wave form of the three-phase generator on open circuit. Series Y of Fig. 12 and Series Y^1 of Fig. 13 are E. M. F. wave forms taken off the generator and receiver secondary terminals, respectively, under the same conditions of load and simultaneous conditions of operation, with leading phase displacement. These wave forms are very similar,

1. These wave forms were taken by Mr. E. F. Bracken, B.S., in Electrical Engineering, University of Illinois, by the method described in his thesis on "Investigation of the Wave Forms of Alternators and Synchronous Converters," June, 1901.

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but the receiver end is distorted more than the one from that of the generator end, as the receiver end power factor was somewhat lower. They show the flattening due to the capacity effect of the leading currents present.

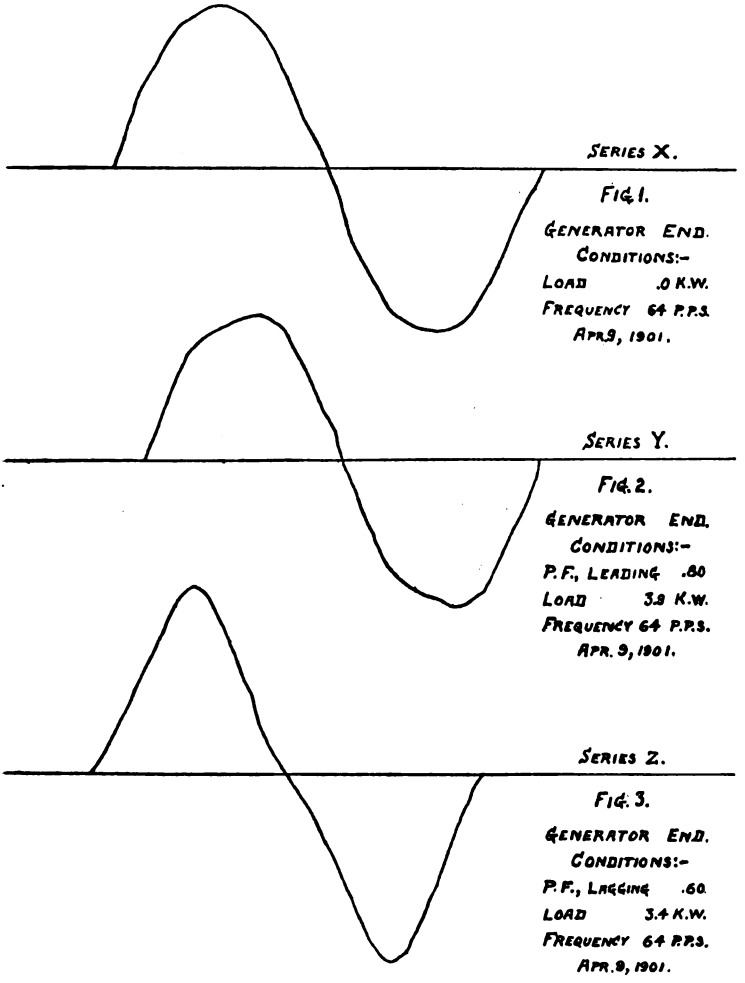

FIG. 12.—Wave Forms from the Generator.

Series z of Fig. 12 and Series z^1 of Fig. 13 are E. M. F. wave forms taken off the generator and receiver secondary terminals under the same conditions of load and simultaneous conditions of operation, but with decided lagging phase displacement. These waves are also similar, but that of the receiver end is more distorted than that of the generator, due to a lower power factor at

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the generator end. These waves illustrate the effect of lagging currents and show the characteristic peak due to the presence of inductance. From examination of them it is evident that to wave-form peculiarities are to be attributed many cases of bad regulation and other difficulties appearing in the earlier transmission systems with mixed apparatus and uncertain line conditions. They illustrate also the great influence upon the E. M. F. waves of the line and generator of the phase relation between the E. M. F. and the current.

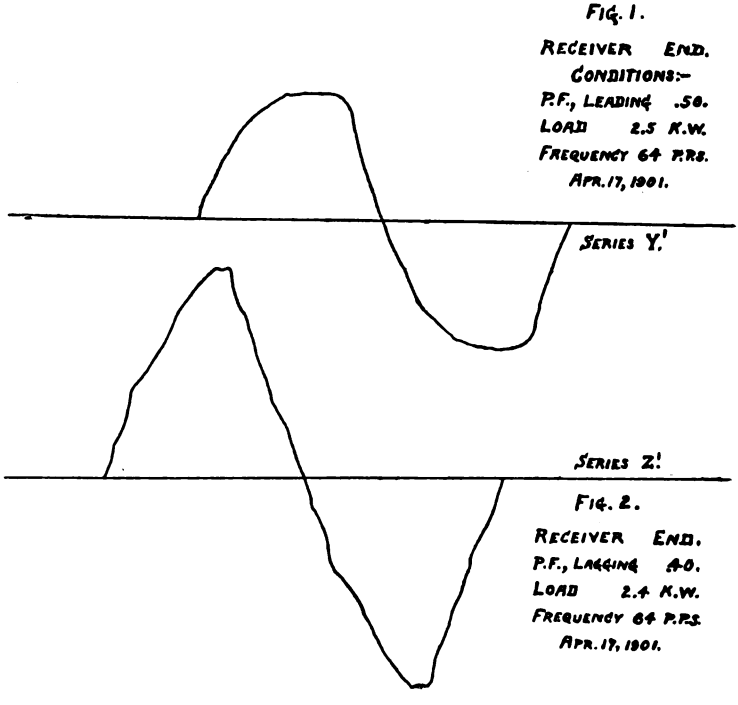

Fig. 13.—Wave Forms from the Receiver Secondary Terminals.

If synchronous motors or converters are used, giving wave forms quite different from those of their impressed E. M. F., they will become very unstable in regard to remaining in synchronism. This dissimilarity of wave forms also necessitates excessive currents, without any regard to the accompanying disadvantages inherent in phase displacement of synchronous machines, and such dissimilarities are purely relative and do not materially concern the question of the intrinsic value of synchronous machines in effecting neutralization of phase displacement.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, Buffalo, August 22, 1901, President Steinmetz in the Chair.

ELEMENTS OF DESIGN PARTICULARLY PERTAINING TO LONG DISTANCE TRANSMISSION.

BY F. A. C. PERRINE.

The popular admiration of a big thing is not unwarranted from an engineering standpoint. The mere bigness of an engineering problem oftentimes introduces new elements into the solution. Ordinary methods of handling materials become impracticable when the size of the work passes that usually undertaken, stresses heretofore unconsidered become important and introduce great difficulties by reason of the extra precautions necessary in their consideration. The electrical transmission problem is no exception to this general rule, for, were it always necessary to consider all the phenomena involved in every electrical transmission problem, the solution of a great long distance problem would be the same as that for the smallest piece of work, since the introduction of larger figures into an equation introduces no difficulties in the solution. But this is not the case. In short distance work there are less terms in the equation than there are in long distance work, and in handling extremely high potentials we must consider not only the electrical factors of safety, but also mechanical factors of safety, for the reason that good insulations are never materials of great strength, and can be relied upon for their mechanical properties only when the mechanical strains are unimportant in comparison with the size of the insulating pieces employed. Were it not for these considerations it might be more expensive to transmit 10,000 K. W. one hundred miles than to transmit the same amount of power a

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single mile, but to the competent electrician not more difficult. All of the phenomena which must be considered in short distance work are introduced into long distance problems in the same form. The difficulty in long distance transmission problems lies in the introduction of phenomena which are not new, but which, as has already been said, are important only in work of the latter class.

No new interpretation of Ohm's law becomes necessary as resistance rises and our lines become long, and the loss of energy over a wire of a given resistance due to its resistance remains unchanged, though, of course, we must always give due consideration to the false resistance effects that may be introduced by the size of the conductors employed. In the earlier transmission lines where distances of from 10 to 20 miles were considered, and voltages from five to 20,000 volts employed, investors hesitated to buy the amount of conductor material necessary to reduce the losses, to amounts of the order employed in short distance work, and in consequence with resistance losses amounting to from 20 to 30% while the regulation problems were of great difficulty, the wires were small, and the false resistance or so-called "skin effects" unnoticed. But with the continued success that has attended the introduction of long distance lines, the investors who have had sufficient courage to approach the problem of transmitting great powers over great distances have felt it unnecessary to restrict the engineers in the quantity of material, and, in consequence, the most recent systems have employed conductors of such a size as to necessitate the consideration of these phenomena a matter of no great difficulty to be sure, and one which only determines the limit of size of a single line. This problem has been further simplified by an agreement between the engineer and the investor that for permanence of supply duplicate lines seem almost necessary.

Perhaps the most important question to face in the long distance transmission is that of regulation. In working short lines, even with alternating currents, the regulation as the load changes is determined almost completely by the resistance effect. Occasionally when heavier currents are employed the self-inductive effects have to be considered, and generally the mutual induction from and to other lines becomes an important factor, though in determining the question of regulation the capacity effects are entirely unimportant.

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Whether the lines are long or short, the current small or great, self-induction, mutual induction, and capacity, as well as resistance are ever present as phenomena. But while with short lines the capacity is the least important of these phonomena and is so unimportant as to be absolutely unconsidered, with long distance lines it becomes the predominant factor. The importance of the capacity factor increases with the quantity of the charging current. This quantity, of course, depends upon the capacity of the circuit, the voltage employed, and the periodicity. A long distance line would be commercially unsuccessful were not the highest possible voltages used, and the usefulness of the current rises, within certain limits, with the periodicity. Accordingly, in long distance lines where periodicities are employed from which incandescent and arc lighting may be directly performed, high voltages entail very great charging currents to such an extent that in a line of 100 miles in length, operating at a voltage of 50 or 60,000 volts and a periodicity of 60, the charging current amounts to something in excess of 2,000 kilovolt amperes, and employs such a proportion of the capacity at the station for charging the idle lines as to make the introduction of units smaller than 2,000 K. W. inadvisable, and renders commercially impracticable the transmission of powers less than about 3,000 K. W., unless the capacity effect be neutralized by the use of reactive coils.

Following the capacity in important effect on regulation is the self-induction. While the mutual induction may become another factor, it is only considered in order to be eliminated by transposition of the wires, all of which leaves of the three final factors involved, the resistance of the line in the most unimportant place, though in short distance work it is the determining factor. The elimination of mutual induction by transposition is generally an exceedingly simple problem, for the reason that the lines are almost invariably few in number and follow each other with constant load for considerable distances, allowing the transpositions to be readily made at or between poles where every facility is offered for making them simply. The self-inductive effects, while important, and increased by the length of the lines, are nevertheless comparatively small in reference to the total amount of power transmitted, for the reason that the high voltages decrease the quantity of current, and so far as the line is concerned, the self-induction is rather a benefit than a detriment

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when the loads are onstant, since the leading current due to capacity is relatively so large. Self-induction does indeed impair the regulation as the load changes and the more nearly the line capacity is balanced by outside inductances the more important becomes the effect of the self-induction except where the load is absorbed by synchronous motors, rotary transformers, or other apparatus which is capable of operating with a leading power factor, in which case the line capacity may be balanced by some form of load having a constant inductance and the line inductance balanced by a leading load variable with the reactance drop along the line. Indeed were it always possible to install long distance lines with a constant inductive load capable of neutralizing altogether the capacity effect; a variable synchronous motor or other leading load adjusted to neutralize at all times the self induction of the line; the problem of regulation in a long distance power transmission line would be reduced to the simplicity of the regulation in short direct current transmissions. With variable loads the capacity and self-inductive effects cannot truly be said to neutralize each other for the reason that the capacity effect is constant, and the self-inductive effect variable with the load, and where a long line is loaded altogether with lagging loads the conditions for regulation are the worst possible. This will be explained later, as we now further discuss the effect of capacity. One of the most noticeable effects of capacity is its action in reference to the wave form of the generators. Should a peaked electro-motive force wave form be delivered by the generators to a line containing a heavy capacity, the line would usually have the effect of somewhat neutralizing the generator defects, furnishing to the translating devices at the delivery end of the line a smoother curve than was originally delivered by the generator, but where the generator curve is a sine curve, or as is more common with modern types of generators, a curve with a slightly flattened top, the capacity tends to increase this flattening at the same time in the current curve all harmonics are accentuated by the presence of capacity in the line and receiving circuit. The extent of this action is illustrated in Figs. 1 and 2, which are reproduced from oscillagraph curves taken by Prof. E. E. Farmer, of the Stanford University, from the lines of the Independent Electric Light Co., of San Francisco. This company is not operating a long distance transmission system, but its circuits being all underground are of a high capacity and in consequence the necessary

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points are illustrated by these curves. In Fig. 1 the smooth curve is the electromotive force curve at the generating end of the line. The rough curve being the corresponding current curve, the lines being unloaded except by reason of the capacity current. Fig. 2 is the same current curve as it is found at a point distant from the power-house along the cables.

The peaked character of the current curves in this case seems to be due to harmonics from the armature slots in the generator, since they correspond in number and position to these slots. That this is not due to any errors in the oscillagraph itself is shown in Fig. 3, which gives the electromotive force curve taken with both the

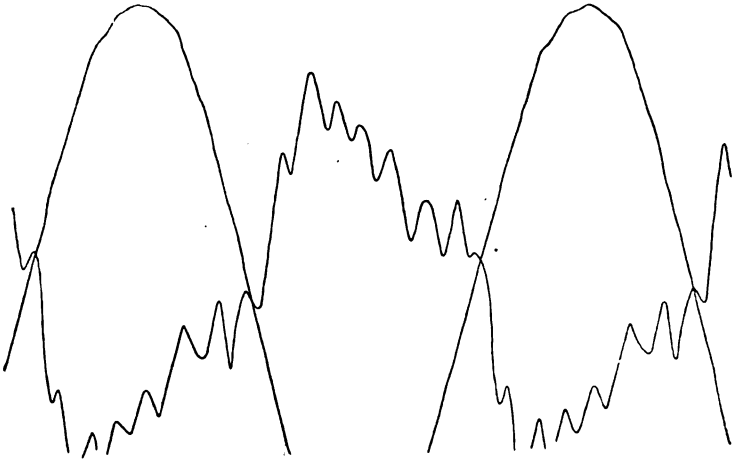

FIG .1.

FIG. 2.

current and electromotive force windings of the oscillagraph in series, and shows that the two windings give corresponding results when operated by the same wave form, but displaced in phase 90°. Fig. 2 shows at once by examination that the effect of the circuit has been to reduce the accentuation of the teeth of the current curve so illustrating the points made. The disadvantages that may arise from this condition were illustrated in the writer's practice in a line 45 miles in length, operated at 60 cycles and

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25,000 volts. A synchronous motor was employed having a naturally bad wave form, the maximum point of the wave rising far above the point represented by the equivalent sine wave. In this case at no load the motor took full load current, and at full load a current much in excess of the normal. The difficulty was remedied by paralleling the lines at the delivery end with a reactance coil. These experiments have been described in detail by the writer in a paper[1] presented May 17, 1900, before this society. These results have been borne out more recently by observations made on a 140-mile line supplying synchronous motors of a better design, one synchronous motor being of the revolving field type, and another of the inductor type. Both of these motors give a fairly correct wave form, and in neither of them the diffi-

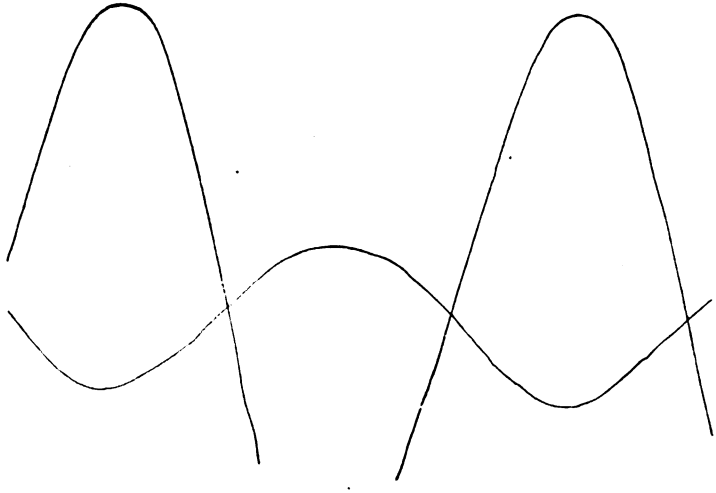

FIG. 3.

culty of the earlier experiments has been repeated, fortunately proving that the difficulty from modifications of the wave form in lines due to the capacity, can be overcome by the choice of correct motors. By far the most important effect of the capacity relates to the regulation of the transformers and generators attached to the line: a leading current taken from such apparatus having the effect of increasing the voltage, while a lagging current decreases it proportionately. This has nothing to do with the drop in voltage from the line itself, whether on account of resistance or self-induction, or to the rise along the line due to the capacity, but refers only to the action of the generating apparatus, and it

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can readily be seen that where a line is operated sometimes with no load and sometimes at full load, the change of the power factor from leading to lagging will change the voltage beyond the calculated drop along the lines, and generally beyond the amounts allowed for in any regulating apparatus. Considering this point we see at once that the regulation difficulty that was above spoken of is due to the variability of the self-inductive effect in the line itself, and points to the conclusions that were above drawn of the perfect line being one in which the capacity of the line is neutralized by a constant self-induction and the self-inductive effect of the line is neutralized by a leading load variable with the variations of the load on the line. With lines of high capacity there is a rise in potential along the circuit, but though this effect has produced much discussion, its practical effect in importance is not very great, for the reason that it is entirely overshadowed by its corresponding effect on the apparatus which has just been described. In the case of the longest lines at present operated, this effect does not amount to more than 20% of the rise in the step-up transformers produced by the same leading current.

As has already been said, the highest possible potentials are necessary in order to restrict the investment in very long transmission lines. When the voltages rise above 30,000 volts, phenomena become important in the problem of insulation which below that voltage were unnecessary to consider. In the first place voltages from 25,000 to 30,000 volts can be readily handled with insulators of either glass or porcelain having a diameter not exceeding seven inches. Pieces of glass or porcelain of these dimensions are mechanically strong and are readily manufactured. Where the voltage rises to 50,000 to 60,000 volts, and the sparking distance between the lines increases to between five and six inches, the insulators must have a diameter of at least 12 or 13 inches and be held not less than 7 or 8 inches above the cross-arm. Such pieces of these fragile insulating materials are difficult to manufacture, and though the problem has been successfully solved, the greatest care in design and manufacture is absolutely essential, though it is believed that the factor of safety of high potential insulators as at present designed is by no means as great as that commonly employed with the lower voltages. An even more striking difficulty in handling high voltages lies in the effect of the electrical surface tension or density which, with high voltages and small wires results in a brush dis-

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charge and high energy loss, independent of leakage over the surface of the insulators, being simply an escape to surrounding bodies from the whole surface of the wire. Among the figures in tables giving the power loss for different voltages obtained by Mershon as the result of his able experiments at Telluride, this effect is apparent, but it did not attract much attention at that time, and the phenomenon, we believe, was first understood and taken into account by the engineers associated with the writer in carrying out high voltage work. Stated simply, it is found that the electrical tension along the line operating at 50,000 or 60,000 volts renders the use of wires smaller than about $\frac{3}{8}''$ diameter a dangerous expedient, resulting in important losses, which again points to the fact that high potential long distance transmissions cannot be successfully carried out unless the power to be transmitted is in itself large, warranting the use of conductors of great size.

The important phenomena which rise to view in carrying out the long distance problem have now been presented, and it remains only to call attention to the fact that in this long distance transmission work extraordinary precautions must be taken to maintain the permanence of supply. Long distance transmission means, as we have said, large powers; and large powers delivered at distant points presuppose important engineering undertakings at the delivery end of the line which call for absolute continuity of supply. The poles must be selected and erected with more than ordinary care. The lines must be constantly patrolled. Trees cannot be simply trimmed, but a right of way almost as wide as a railroad right of way secured, and all obstructions of the nature of trees which may fall across the line in high winds removed. The use of the ordinary insulating materials in power-houses and supply stations, such as paraffined wood and paraffined marble, must be entirely abandoned or relied upon only as minor auxiliaries, and, finally, wherever it is possible, either steam or storage battery auxiliaries at the delivery end of the line furnished. It seems almost unnecessary to call attention to the design of the apparatus in the generating station, but it is perhaps well to mention the fact that the generator and transformer designers may aid the installing engineer very materially by paying particular attention to regulation at the lower power factors even at the cost of some efficiency, should that be necessary. The designer should always remember that regulation in long distance transmission is regulation at other than unity power factor.

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The engineering problem, therefore, by its very bigness is one requiring the most careful solution at its every step, and the fact that it is being now successfully carried out merits the highest praise both toward the engineers in designing, and the investors whose faith in their engineers permits the employment of the necessary capital to do the work thoroughly.

The points made in this paper have all at one time or another been particularly discussed before the INSTITUTE, and the writer only ventures to bring them together in this sketch in the hope that new points of view may be attained by their discussion in relation to the whole problem.

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A paper read at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22, 1901. President Steinmetz in the Chair.

THE INDUCTION MOTOR AND THE ROTARY CONVERTER AND THEIR RELATION TO THE TRANSMISSION SYSTEM.

BY CHAS. F. SCOTT.

Two important functions of an alternating current transmission system are the production of mechanical power and the furnishing of direct current.

The induction motor and the rotary converter have become the usual means of transforming energy into these forms. The wide extent to which they are now used is a notable feature of recent electrical progress. An examination of their behavior in service, especially in connection with other apparatus which might be used for the same purposes, will indicate the particular characteristics which have made them so successful. Occasion will be taken also to note some of the important inter-relations between the various kinds of receiving apparatus and the transmission circuit and the generators by which they are supplied with current.

I.—The Induction Motor.

Power may be produced by the synchronous motor or by the induction motor. A comparison between the two motors may be made by placing in parallel columns their respective characteristics in services, *i. e.*, those which concern the operation rather than the design. An induction motor with a secondary of the "squirrel cage" type, started by applying a low E. M. F. to the primary, is taken for comparison—the description will require modification in some particulars if the secondary circuit is provided with adjustable resistance. These are of minor importance and do not affect the general comparison.

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Synchronous Motor.	Induction Motor.
AUXILIARY APPARATUS.	
1. A starting motor; or, if self-starting, some form of resistance or transformer for reducing the voltage.	1. A two-way main switch with auto transformers giving a low E. M. F. for starting. This may be located at any distance from the motor.
2. An exciter, driven by the motor or otherwise, with circuits to switchboard and motor.	2. No exciter is required.
3. Rheostats for exciter and motor.	3. No field rheostats are required.
4. Instruments for indicating when field current is properly adjusted.	4. No instruments are required.
5. Main switch and exciter switches.	5. No exciter switches are required.
6. A friction clutch is required in many cases.	6. No friction clutch is required, as the motor starts its load.
CONSTRUCTION.	
1. Armature winding.	1. Primary winding.
2. Field winding with many turns. Liable to accident from "field discharge" if exciting current is suddenly broken; or from high E. M. F. by induction from the armature if the field circuit is open.	2. Secondary, short-circuited.
3. Collector rings and brushes.	3. No moving contacts on "squirrel cage" secondary.
STARTING—NORMAL.	
1. Motor is brought up to speed without load; if starting motor is used, the main motor must be brought to proper speed and "synchronized"; if self-starting, the starting devices must be cut out of circuit at proper time.	1. Throw switch to starting and then to running position.
2. Exciter is made ready for delivering proper current and the motor field must be excited, adjustments being made by rheostats until instruments give proper indication.	2. There is no exciter. (The motor is magnetized by lagging current from the generator.)
3. Load is thrown on by friction clutch or other means.	3. The motor starts its own load.

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Synchronous Motor.	Induction Motor.
STARTING—ABNORMAL.	
1. If the several operations in starting be performed improperly or in wrong order injury may result. If a starting motor is used the synchronizing may be attempted at an improper speed or phase; if the motor is self-starting and it is connected to the circuit without the starting devices a large current will flow which may induce a high E. M. F. in the field circuit; if the field circuit be open a high E. M. F. may be induced in it at other times also.	1. The only possible error is in starting with the switch in the running or full voltage position, which simply causes the motor to exert a greater torque and consume a greater current than is necessary.
2. If a load having inertia be applied by closing the friction clutch too quickly the motor may be overloaded and stopped.	2. The motor starts its own load and requires no friction clutch.
3. If motor stops owing to failure of current supply, it is not self-starting when the current returns. An attendant is always required for starting.	3. The motor will stop if the current is cut off at the power house and then start again when the current is supplied to the circuit.
STARTING AND MAXIMUM RUNNING TORQUE.	
1. The starting torque of the self-starting motor is very small and an excessive current is required for developing it. The motor starts as an induction motor, but inefficiently, as the design which is best for synchronous running, is not good for starting.	1. The starting torque is adjustable and may be several times full load torque.
2. The maximum torque is several times the full load torque, and occurs at synchronous speed; below this speed the torque is very small; any condition which momentarily lowers the speed causes the motor to stop.	2. The maximum torque is usually greater than that of the synchronous motor, but it occurs at a reduced speed and there is a large torque at lower speeds.

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Synchronous Motor.	Induction Motor.
SPEED.	
1. The motor has a single definite speed; at other speeds its torque is very small and the current is very large.	1. The motor may be designed for a practically constant speed, with large torque at lower speeds; or for several definite speeds by changing the number of poles; or for variable speed work, such as is required for cranes, elevators, hoists and the like.
CURRENT.	
1. If there is useful starting torque the current required for producing it is very great.	1. The starting current may be made proportional to the torque, and is $1\frac{1}{2}$ to $2\frac{1}{2}$ times that required for the same torque at high speed.
2. The running current depends upon the wave form. If the wave form of the motor and of the circuit differs, a corrective current will follow, which cannot be eliminated by adjustment of field excitation.	2. The running current is practically independent of the difference in wave form, as it has no wave form of its own.
3. The running current depends upon uniformity of alternations of the current, *i. e.*, upon the uniformity of the speed of the generator and other synchronous motors. The motors attempt to follow the generator speed exactly. If the latter pulsates, the motors pulsate also; they vibrate about a mean position, "hunting" or "pumping." One motor pumping incites others. The current is increased even though the conditions may still be operative.	3. The current is practically independent of fluctuations in generator speed, as there is a slip between the synchronous and the actual speed of the motor.
4. The running current depends upon the relation between the field current (which is adjusted by the attendant) and the E. M. F. of the circuit. The main current may be made leading or lagging or theoretically it may be neither. The E. M. F. of the circuit is an element which is under the partial control of the attendants at every motor as well as at the generator station.	4. The current is not subject to any adjustments which the motor attendant can make, nor is the E. M. F. of the circuit in any way under his control.

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Synchronous Motor.	Induction Motor.
POWER FACTOR.	
1. As the power factor is the relation between actual current and energy-current, it is dependent upon wave form, hunting and field current. Under favorable conditions the motor may have a high power factor; under many actual conditions it may not; under some conditions the highest attainable power factor is less than that of the induction motor.	1. The power factor varies with load, but is definite and is practically independent of wave form and hunting.
2. The current may be lagging or leading, depending upon the motor field strength.	2. The current to the motor is always a lagging current.
REACTION UPON GENERATOR AND CIRCUIT.	
1. The motor impresses its own wave form on the circuit.	1. The motor has no wave form to impress upon the circuit; its tendency is to smooth out irregularities in a wave which is not a sine wave.
2. A motor may augment the fluctuations in generator speed by the oscillation of its own armature. One motor may increase the disturbance in the circuit so as to interfere with other motors which would not have been seriously affected.	2. The motor has a damping action upon fluctuations in frequency; in some cases a synchronous motor which hunts may run smoothly when an induction motor is connected to the same circuit.
3. As the current may be either lagging or leading, the drop in E. M. F. in the generator and between generator and motor may be either more or less than that which could be caused by a non-inductive load or by an induction motor.	3. The drop in the E. M. F. is always greater than would be caused by non-inductive load.
4. If a short-circuit occurs in the transmission system the motor acts as a generator, which thereby greatly increases the current and the intensity of the short-circuit.	4. The motor does not generate current when there is a short circuit.

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Synchronous Motor.	Induction Motor.
REACTION UPON GENERATOR AND CIRCUIT.—Continued.	
5. If the circuit is opened, either by a switch, a circuit breaker, a fuse or the breaking of the line, the motor speed falls, its E. M. F. is no longer in phase with that of the circuit; the two are thereby added, thus doubling the normal E. M. F. and bringing increased strains on the insulation and the opening devices.	5. The motor does not generate E. M. F. when it is disconnected from the circuit.
CAUSES WHICH MAY ACCIDENTALLY STOP A MOTOR.	
1. Momentary lowering of E. M. F. caused by short-circuit on the line, or by accident at another motor, or by error in synchronizing a generator, or by the "switching over" of the motor from one circuit to another, is apt to cause the motor, particularly if carrying load, to fall from synchronism and come to rest.	2. Momentary lowering of E. M. F. causes momentary decrease in speed.
2. A heavy load, even momentary, may exceed the limiting torque and cause the motor to drop from synchronism, even though the load be removed immediately. The connection between generator and motor is rigid.	2. An excessive load receives the stored energy of the motor and of the load itself as the motor falls; when the excess load is removed the motor speed increases again. The connection between generator and motor is elastic.
3. If the generator speed suddenly increases, a motor carrying a load having inertia may be unable to increase its speed quickly without exceeding the limiting torque, which will cause the motor to stop.	3. The motor readily follows changes in generator speed.
SUMMARY.	
1. The motor is an *active* element in the system; it acts as a generator in impressing its own wave form, its E. M. F. and its fluctuations upon the circuit. These fluctuations may be caused by an intermittent load.	1. The motor is a *passive* element in the system. Each motor attends to its own work and does not try to run the system.

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Synchronous Motor.	Induction Motor.

SUMMARY.—Continued.

2. The motor is a sensitive element in the system. Its successful operation is dependent upon a proper relation between the design of the motor itself and of other machines connected with the system. Its successful operation also depends upon the proper adjustment and freedom from speed fluctuation in generators and other motors. It is liable to momentary variations from normal conditions, such as a sudden overload and sudden increase of generator speed or a momentary fall in E. M. F.	2 The motor is not sensitive to differences in the design of other apparatus operating on the same system.
3. The motor requires skill and care on the part of the attendant for starting, for readjusting and for keeping the various brushes and auxiliary apparatus in proper condition.	3. No experience and electrical skill are required of the attendant and there is little or nothing to get out of order either through carelessness or design.
4. The power factor is under the control of the operator and the current may be made leading or lagging. Instruments are necessary in order that proper adjustments may be made by the attendant.	4. The motor has a definite power factor, depending upon the load; the out-of-phase current does not vary greatly at different loads. The changing load, therefore, has comparatively little effect upon the drop in voltage, and in regular service there is little liability that the motor will disturb the E. M. F. of the circuit.
5. The motor and its operation are complex and involve many possibilities of accident.	5. The motor and its operation are simple and reliable.

The synchronous motor is obviously not suitable for general distribution of power, owing particularly to its lack of starting torque, the skill required in attendance and the liability of the motor to stop if the conditions become abnormal. These objectionable features, however, are of much less importance when motors are installed in sub-stations or are of sufficiently large size to justify an attendant.

The characteristic of the synchronous motor which may be particularly advantageous is the fact that the power factor of the current can be varied and that the current may be made leading. In this way the current required and the drop in the generator

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and transmission circuit may be reduced. If the motor is used on a circuit supplying induction motors the synchronous motor may be given a leading current, thus neutralizing the lagging current to other motors. The extra current taken by the synchronous motor for this compensation necessitates a larger size than would otherwise be required.

The characteristic of the induction motor which is usually regarded as most unfavorable in comparison with the synchronous motor, is the fact that its current is always a lagging current. In a comparison with synchronous motors only large sizes should be included, as synchronous motors of small size are not to be seriously considered in practical work. The induction motors of large size have relatively high power factors, *i. e.*, the out-of-phase current is small. Moreover, this current is definite in kind and nearly constant for different loads, so that it is a definite and constant element which may be provided for. It may therefore create less disturbance on the system than the out-of-phase current of the synchronous motor, which is either lagging or leading, large or small, depending upon the intelligence and care of the attendant and upon other conditions. In one case the voltage of the system is under the control of the attendant in the power-house and the lagging current to induction motors which are running with either constant or varying load is practically constant. On the other hand, when synchronous motors are used, the voltage of the system is dependent upon all the motors, and uncertain or disastrous results are liable to be caused by adjustments by the various motor attendants. In many cases it is far better to provide the generators and circuits suitable for supplying the lagging current required by induction motors, rather than to attempt to gain the theoretical advantages attending the use of synchronous motors, as the securing of these advantages requires that so many conditions be favorable. At best the synchronous motor is less satisfactory to operate and is far more sensitive to abnormal or emergency conditions than the induction motor.

The foregoing considerations will indicate why it is that the induction motor has taken such a leading place, while the synchronous motor has been less favored and is now rarely considered seriously as a competitor of the induction motor except in large sizes.

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II.—The Rotary Converter.

The rotary converter is in its relation to the transmission system essentially a synchronous motor. The foregoing characteristics of the synchronous motor, except those which involve a load upon the motor, apply also to the rotary converter. The starting, however, is somewhat simpler, as there is no load to accelerate except the armature. No separate exciter is necessary as the converter can furnish its own direct current for exciting. A converter may be compound-wound so that as it is loaded the increased excitation changes the out-of-phase current in such a way as to compound the voltage, thus overcoming the drop which would otherwise occur in generator and transmission circuits; whereas, the synchronous motor would cause a falling off in voltage. The rotary converter is generally used in units of considerable size placed in sub-stations having skilled attendants. For these reasons the operation of rotary converters does not involve so many difficulties as that of synchronous motors.

Direct current is obtained from alternating circuits, either by the rotary converter or a motor-generator, in which either a synchronous or an induction motor is employed.

The rotary converter has the advantage over the motor-generator in point of cost, there being but one machine instead of two; in point of efficiency, there being the loss in one machine instead of two; and in its effect upon the voltage of the transmission system, as it may be compounded to overcome the drop which would otherwise occur in generator and transmission circuit. On the other hand, the E. M. F. of the direct current delivered by the converter depends upon the E. M. F. received; whereas, the E. M. F. of a motor-driven generator is independent of the E. M. F. of the supply circuit and may be adjusted or compounded as may be desired. It is found in practice, however, that the voltage delivered by a rotary converter can be satisfactorily adjusted and controlled by regulating devices or by compounding so that usually the close relation between the E. M. F.'s at the two ends of the converter is not disadvantageous, provided the E. M. F. of the supply circuit is reasonably constant.

This statement applies to those cases in which a practically constant voltage is desired. There are, of course, special cases in which the voltage is to be adjusted over a very wide range or where for other reasons the motor-generator is to be preferred.

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In many cases the motor may be used either with or without transformers, whereas they would be required with a rotary converter.

A motor generator employing a synchronous motor does not seem to possess any essential advantage over the converter except that sometimes the motor may receive the line voltage without transformers, and in some cases the independent control of the direct current voltage is desired. The use of the synchronous motor does not remove the objections to the rotary converter, which are based on the fact that it is a synchronous machine.

A motor-generator employing an induction motor has the advantage of employing induction instead of synchronous apparatus; thereby securing many of the advantages set forth in the comparison between synchronous and induction motors. Circuits which are supplied by generators in which the speed has a rapid and periodic fluctuation, or in which for any other reason the use of a synchronous machine is impracticable or undesirable, may nevertheless operate an induction motor driving a generator with full satisfaction. The various characteristics of the induction motor under emergency conditions, such as sudden overload, momentary interruption or lowering of the voltage of the supply circuit, may cause little or no inconvenience if the induction motor is used, whereas, it might cause serious interruption to a rotary converter or a synchronously driven generator. The induction motor driving a generator is also to be preferred where units are quite small and the attendance is unskilled. The rotary converter, like the synchronous motor, is unsuited for general distribution in small units.

The foregoing statements and comparisons involving the rotary converter doubtless comprise the principal reasons why this apparatus is being so widely adapted and is in such general use. To indicate the wide use of this apparatus it may be stated that the Westinghouse Electric and Manufacturing Company, with which the writer is connected, has sold over 400 rotary converters. Of this number 30 per cent. are for a frequency of 60 cycles or more. The aggregate output is over 165,000 K. W.

Most of this apparatus is now installed and is in successful operation. In fact, the difficulties in connection with the installation and operation of rotary converters on circuits which are suited for them are trivial and do not materially differ in amount

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from those which may be expected to occur in connection with other kinds of apparatus.

The very wide use of the induction motor and the rotary converter is an established fact, and it is believed that many of the reasons for their selection in preference to other kinds of apparatus have been set forth in the foregoing notes.

III.—The Alternator.

Many of the specific relations between the induction motor and the rotary converter and the supply system have been indicated. There is obviously a close relation between the alternator and the apparatus which it supplies. The conditions are radically different from those involved in incandescent lighting. An alternator which may be quite satisfactory for lighting purposes may be highly inadequate for successfully supplying current for either induction motors or rotary converters.

For supplying current to induction motors an alternator should have good inherent regulation. The lagging current taken by induction motors requires a greater increase in field current for maintaining a given voltage than is required when the load is non-inductive. In order that the field current may not be excessive, the generator should be properly proportioned to have close regulation. The adjustment of the field current by external devices is not a wholly satisfactory substitute for close inherent regulation. Suddenly changing loads or the throwing on or off of motors causes fluctuations in voltage, as the external devices cannot act quickly enough to prevent the disturbance. The necessity of good inherent regulation is all the more necessary where the motors are large in proportion to the size of the generator and where loads are fluctuating.

For the operation of rotary converters the generator speed should be uniform. Engines which are sufficiently uniform in angular velocity to enable generators to run successfully in multiple may nevertheless be unsuited for operating rotary converters or synchronous motors. It is preferable also that generators for operating rotary converters should have good inherent regulation, not only in order that the E. M. F. may be maintained at heavy loads, but also for the purpose of holding the converter rigidly in synchronism. If the alternating field is comparatively weak, as is usual in machines of poor regulation, there may be a shifting of the magnetic field back and forth with different arma-

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ture currents, quite similar to the shifting of lead in direct current machines. It is obvious that if the effective position of the field poles may shift back and forth, this shifting is comparable with fluctuations in generator speed, and becomes a source of unsteadiness in the system which may contribute to the "hunting" of rotary converters. This shifting may occur also in a machine having a strong field if a large proportion of the magnetizing force is absorbed in the iron of the field magnet, *i. e.*, a machine with a saturated field. Such a machine may have good E. M. F. regulation, and still be of an inferior type for the driving of synchronous machinery.

It follows, therefore, that a generator which is to supply induction motors or rotary converters should be selected with reference to the service which it is to supply. In some cases unsatisfactory results have been obtained in the use of motors or converters, duplicates of those which have given full satisfaction elsewhere. The trouble has been located in fluctuating speed or in the characteristics of the alternator supplying the current.

A transmission system must be considered as a unit and the inter-relation between the alternator and the apparatus to which it supplies power must be fully considered.

The theoretical arguments which are occasionally urged against the alternating system, the induction motor and the rotary converter, find their most effective answer in the plants which are now in operation and in their record of service.

The induction motor and the rotary converter to-day represent the survival of the fittest, and confirm the judgment of those engineers who have consistently and persistently advocated their use.

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THEORETICAL INVESTIGATION OF SOME OSCILLATIONS OF EXTREMELY HIGH POTENTIAL IN ALTERNATING HIGH POTENTIAL TRANSMISSIONS.

BY CHARLES PROTEUS STEINMETZ.

In the following I intend to give a section of a series of investigations extending over some years, on the effect of the exponential term in the general equation of alternating current:

If a sine wave of E M. F. is impressed upon a general electric circuit containing resistance, inductance and capacity, the ultimate current is a sine wave also. In the moment of closing the circuit, however, or in any other way changing the circuit conditions, upon the sine wave of current an exponential term is superimposed, of the general character:

$$\Sigma A_1 \varepsilon^{-a_1 \varphi}$$

In a single circuit containing only resistance r and inductive reactance x, only one exponential term

$$A\varepsilon^{\frac{r}{x}\varphi}$$

appears. In a system of such circuits, directly or inductively connected with each other, a series of exponential terms appear,

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the exponents of which are determined as the roots of an equation of nth degree.

If, however, a circuit contains resistance, inductance and capacity in series, two exponential terms

$$A_1 \varepsilon^{-a_1 \varphi} + A_2 \varepsilon^{-a_2 \varphi}$$

exist, where a_1 and a_2 are the roots of a quadratic equation, and either real or complex imaginary. In the latter case the exponential term resolves into the form:

$$\varepsilon^{-b \varphi} \left\{ B_1 \cos \varphi + B_2 \sin \varphi \right\}$$

an electric oscillation.

With several circuits of general character connected with each other directly or inductively, a series of exponential terms

$$\Sigma A_1 \varepsilon^{-a_1 \varphi}$$

appear, in which the exponents a_1 are the roots of an equation of $2n$th degree, which, when complex imaginary, give electrical oscillations, and the coefficients A_1 depend on the initial conditions of the circuits. Thus in such a system of circuits a number of superimposed oscillations may occur, of different frequencies and intensities.

Under certain conditions by such oscillations caused by a change of circuit conditions, destructive voltages may be produced.

The first time I noticed such a phenomenon was when making a series of observations on the effect of opening a high potential circuit with different types of circuit-breakers, on an artificial line consisting of inductive coils and about half a mile of high potential cable, with a spark gap between needle points connected across the system, to measure an instantaneous rise of voltage. If the needle points were brought so close together that a discharge occurred between them, invariably by the short-circuiting of the system across the needle points, an extremely high voltage was induced locally in the system, of a total striking distance reaching as high as 40″, that is between one-quarter and one-half

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million volts, the normal voltage of the system being about 10,000.

The phenomenon is probably as follows: By striking between the needle points shunting the circuit, the system was short-circuited and thus instantly drained of its electro-static charge, so that the potential locally fell to practically nothing, while an excessive current passed between the needle points as arc. By the heating effect of this current the arc was instantly blown out explosively and thus the short-circuit current of the system ruptured. After the explosion the discharge between the needle points again short-circuited, interrupted itself, etc. The phenomenon is thus of similar character, but infinitely greater power, than the action of the Wehnelt interrupter, the latter depending upon the combined effect of self-induction and electrolytic polarization, while the phenomenon I observed occurred with self-induction and capacity.

Since that time in a number of instances of high potential circuits electrical discharges were noticed, of striking distances many times greater than that of the normal potential of the system, under circumstances where a short-circuiting arc interrupted itself in the open air. A short-circuit in a constrained space, as a buried cable, does not appear to give this effect.

From this and other reasons I was led to believe that a short-circuiting high potential arc in free space, in a system containing self-induction and capacity, is a self-interrupting phenomenon, and thus may cause very serious high potential effects. On any high potential limited power transformer this phenomenon can be observed by an entire change of the character of the arc between the high potential terminals when inserting capacity in shunt. From the flame of the steady and noiseless arc, which curves upward by its heat, the discharge changes to the glaring white, noisy, lightning-like, destructive high potential oscillation. This change can be shown photographically, the photographs giving in the former case, that is absence of capacity, the striations of the successive half waves of the impressed frequency, while in the latter case they show a system of successive electrostatic sparks not followed by the striated alternating arc flame. As shown by Mr. W. S. Andrews, a number of oscillating discharges may occur during the same half wave of alternating primary E. M. F.

The investigation of the character of electric oscillation pro-

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duced by a short-circuiting and self-interrupting arc is the purpose of the following. The bearing of this phenomenon on high potential engineering is obvious.

If in a transmission line of impressed voltage $e = E \cos(\varphi - \omega)$ carrying current $I \cos(\varphi - \omega - \delta)$, the circuit is opened at the receiving end, there remain in circuit the line capacity in series with the resistance and inductance of step-up transformers, etc., and a part of the line.

Let, as an approximation, the line capacity be represented by a condenser shunted across the center of the transmission line, and let:

r = resistance,

L = inductance, thus: $x = 2\pi N L$ = reactance of circuit

between constant potential generator bus-bars and line capacity (reduced to the line voltage).

Let:

C = capacity, thus: $k = \dfrac{1}{2\pi N C}$ = capacity reactance of line.

Let now the circuit be opened at the moment: $t = o$, or: $\varphi = o$, and at the moment when the circuit is opened:

e_0 = potential difference at line condenser,

i_0 = current in line.

If: i = instantaneous value of current at time t, it is: E. M. F. consumed by self-induction:

$$L\frac{di}{dt}$$

Potential difference at condenser terminals:

$$e_1 = \frac{1}{C}\int i\,dt$$

Thus the differential equation of the phenomenon is:

$$e - ir - L\frac{di}{dt} - \frac{1}{C}\int i\,dt = o$$

or, substituting:

$$\varphi = 2\pi N t,$$

$$e = E\cos(\varphi - \omega)$$

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it is:

$$E\cos(\varphi-\omega)-ir-x\frac{di}{d\varphi}-k\int i\,d\varphi=0 \qquad (1)$$

and:

$$e_1=k\int i\,d\varphi=E\cos(\varphi-\omega)-ir-x\frac{di}{d\varphi} \qquad (2)$$

Equation (1) differentiated:

$$E\sin(\varphi-\omega)+k\,i+r\frac{di}{d\varphi}+x\frac{d^2i}{d\varphi^2}=0 \qquad (3)$$

This differential equation of second order is integrated by:

$$i=A\,\epsilon^{-a\varphi}+B\cos(\varphi-\sigma \qquad (4)$$

Substituting (4) in (3) gives:

$$(a^2x-ar+k)\,A\,\epsilon^{a\varphi}+\sin(\varphi+\sigma)\,[E\cos(\sigma-\omega)-rB]$$
$$+\cos(\varphi-\sigma)\,[E\sin(\sigma-\omega)-(x-k)\,B] \qquad (5)$$

Hence:

$$\left.\begin{aligned}&a^2x-ar+k=0\\&E\cos(\sigma-\omega)-rB=0\\&E\sin(\sigma-\omega)-(x-k)\,B=0\end{aligned}\right\} \qquad (6)$$

$$A=\text{indefinite},$$

and herefrom:

$$\tan(\sigma-\omega)=\frac{x-k}{r}$$

or, by denoting:

$$\tan\alpha=\frac{k-x}{r} \qquad (7)$$

where a is a constant of the circuit,

$$\sigma=\omega-\alpha \qquad (8)$$

Further:

$$B=\frac{E}{\sqrt{r^2+(x-k)^2}}$$

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or, denoting:

$$z_0 = \sqrt{r^2 + (x - k)^2} \tag{9}$$

where z_0 is a constant of the circuit,

$$B = \frac{E}{z_0} \tag{10}$$

and α is, as root of a quadratic equation:

$$a = \frac{r \pm \sqrt{r^2 - 4\,x\,k}}{2\,x} .$$

Since the inductive reactance x is of the same magnitude as the resistance r, the capacity reactance k, however, that is the reactance of the line as condenser, of higher magnitude than r or x, it is always:

$$4\,x\,k > r^2$$

that is, $\sqrt{r^2 - 4\,x\,k}$ is imaginary

Substitutiug:

$$q = \sqrt{4\,x\,k - r^2} \tag{11}$$

it is:

$$a = \frac{r \pm j\,q}{2\,x} \tag{12}$$

and the integral equation of the problem is:

$$i = A_1\,\varepsilon^{-\frac{r+jq}{2x}\varphi} + A_2\,\varepsilon^{-\frac{r-jq}{2x}\varphi} + \frac{E}{z_0}\cos(\varphi - \omega + \alpha) \tag{13}$$

that is:

$$i = \varepsilon^{-\frac{r}{2x}\varphi}\left\{A_1\,\varepsilon^{-j\frac{q}{2x}\varphi} + A_2\,\varepsilon^{+j\frac{q}{2x}\varphi}\right\} + \frac{E}{z_0}\cos(\varphi - \omega + \alpha)$$

Substituting the trigonometric expressions:

$$\left.\begin{aligned} \varepsilon^{+j\frac{q}{2x}\varphi} &= \cos\frac{q}{2\,x}\varphi + j\sin\frac{q}{2\,x}\varphi \\ \varepsilon^{-j\frac{q}{2x}\varphi} &= \cos\frac{q}{2\,x}\varphi - j\sin\frac{q}{2\,x}\varphi \end{aligned}\right\}$$

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and rearranging, it is:

$$i = \varepsilon^{-\frac{r}{2x}} \left\{ (A_1 + A_2) \cos \frac{q}{2x} \varphi - j (A_1 - A_2) \sin \frac{q}{2x} \varphi \right\}$$

$$+ \frac{E}{z_0} \cos (\varphi - \omega + \alpha)$$

or, substituting:

$$\left.\begin{aligned} A_1 + A_2 &= C_1 \\ j (A_1 - A_2) &= C_2 \end{aligned}\right\}$$

it is:

$$i = \varepsilon^{-\frac{r}{2x}\varphi} \left(C_1 \cos \frac{q}{2x} \varphi - C_2 \sin \frac{q}{2x} \varphi \right) + \frac{E}{z_0} \cos(\varphi - \omega + \alpha) \quad (14)$$

where

C_1 and C_2 are determined by the circuit conditions at $t = 0$.

The potential difference at the condenser terminals is, by substituting (14) in (2):

$$e_1 = \varepsilon^{-\frac{r}{2x}\varphi} \left\{ C_1 \left(\frac{q}{2} \sin \frac{q}{2x} \varphi - \frac{r}{2} \cos \frac{q}{2x} \varphi \right) + C_2 \left(\frac{q}{2} \cos \frac{q}{2x} \varphi \right. \right.$$

$$\left. \left. + \frac{r}{2} \sin \frac{q}{2x} \varphi \right) \right\}$$

$$+ E \left\{ \cos (\varphi - \omega) - \frac{r}{z_0} \cos (\varphi - \omega + \alpha) + \frac{x}{z_0} \sin (\varphi - \omega + \alpha) \right\}$$

or, substituting:

$$\frac{r}{z_0} = \cos \alpha \quad \frac{x}{z_0} = \frac{k}{z_0} + \sin \alpha :$$

$$e_1 = \varepsilon^{-\frac{r}{2x}\varphi} \left\{ C_1 \left(\frac{q}{2} \sin \frac{q}{2x} \varphi - \frac{r}{2} \cos \frac{q}{2x} \varphi \right) \right.$$

$$\left. + C_2 \left(\frac{q}{2} \cos \frac{q}{2x} \varphi + \frac{r}{2} \sin \frac{q}{2x} \varphi \right) \right\}$$

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$$+\frac{k}{z_0} E \sin(\varphi - \omega + \alpha) \Big\} \qquad (15)$$

At time: $t = 0$, or: $\varphi = 0$, it is, substituting in (14) and (15)

$$\left.\begin{aligned} i_0 &= C_1 + \frac{E}{z_0}\cos(\omega + \alpha) \\ e_0 &= -\frac{r}{2} C_1 + \frac{q}{2} C_2 - \frac{k}{z_0} E \sin(\omega + \alpha) \end{aligned}\right\}$$

and herefrom:

$$\left.\begin{aligned} C_1 &= i_0 - \frac{E}{z_0}\cos(\omega + \alpha) \\ C_2 &= \frac{2 e_0 + r i_0}{q} + \frac{k}{q z_0}[2 k \sin(\omega + \alpha) - r \cos(\omega + \alpha)] \end{aligned}\right\} \qquad (16)$$

Substituting (16) in (14) and (15), gives:

Current:

$$i = \frac{E}{z_0}\cos(\varphi - \omega + \alpha) + \varepsilon^{-\frac{r}{2x}\varphi}\left\{\left[i_0 - \frac{E}{z_0}\cos(\omega + \alpha)\right]\cos\frac{q}{2x}\varphi - \left[\frac{2 e_0 + r i_0}{q} + \frac{E}{q z_0}\left(2 k \sin(\omega + \alpha) - r\cos(\omega + \alpha)\right)\right]\sin\frac{q}{2x}\varphi\right\} \qquad (17)$$

Potential Difference at Condenser:

$$e_1 = \frac{k}{z_0} E \sin(\varphi - \omega + \alpha) + \varepsilon^{-\frac{r}{2x}\varphi}\left\{\left[e_0 + \frac{k}{z_0} E \sin(\omega - \alpha)\right]\cos\frac{q}{2x}\varphi + \left[\frac{2 r e_0 + (r^2 + q^2) i_0}{2 q} + \frac{E}{2 q z_0}(2 k r \sin(\omega - \alpha) - (r^2 + q^2)\cos(\omega - \alpha)\right]\sin\frac{q}{2x}\varphi\right\}$$

These equations (17) can be essentially simplified by neglecting terms of secondary magnitude.

k is in high potential transmission lines or cables always very large compared with r and x.

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The full load resistance and reactance voltage may vary from less than five per cent. to about 20 per cent. of impressed voltage, the charging current of the line from five per cent. to about 20 per cent. of full load current, at normal voltage and frequency.

In this case, k is from 25 to more than 400 times as large as r or x, and r and x thus negligible compared with k.

It is then, in close approximation:

$$\left.\begin{aligned} z_0 &= k \\ q &= 2\sqrt{x\,k} \\ B &= \frac{E}{k} \\ \alpha &= \frac{\pi}{2} = q\ 0^0 \end{aligned}\right\} \qquad (18)$$

Substituting these values in equations (17), gives:

Current:

$$i = -\frac{E}{k}\sin(\varphi - \alpha) + \varepsilon^{-\frac{r}{2x}\varphi}\left\{\left[i_0 - \frac{E}{k}\sin\alpha\right]\cos\sqrt{\frac{k}{x}}\,\varphi - \left[\frac{2\,e_0 + r\,i_0}{2\sqrt{x\,k}} - \frac{E}{2\sqrt{x\,k}}\left(2\cos\omega + \frac{r}{k}\sin\omega\right)\right]\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \qquad (19)$$

Potential Difference at Condenser:

$$e_1 = E\cos(\varphi - \omega) + \varepsilon^{-\frac{r}{2x}\varphi}\left\{[e_0 - E\cos\omega]\cos\sqrt{\frac{k}{x}}\,\varphi + \left[\frac{2\,r\,e_0 + (r^2 + 4\,x\,k)\,i_0}{4\sqrt{x\,k}} - \frac{E}{4\sqrt{x\,k}}\left(2\,r\cos\omega + \frac{r^2 + 4\,x\,k}{k}\sin\varepsilon\right)\right]\sin\sqrt{\frac{k}{x}}\,\varphi\right\}$$

These equations consist of three terms:

$$\left.\begin{aligned} i &= i' + i'' + i''' \\ e_1 &= e_1' + e_1'' + e_1''' \end{aligned}\right\} \qquad (20)$$

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$$\left.\begin{aligned} i' &= -\frac{E}{k}\sin(\varphi-\omega) \\ e_1' &= E\cos(\varphi-\omega) \end{aligned}\right\} \tag{21}$$

$$\left.\begin{aligned} i'' &= -\frac{E}{k}\,\varepsilon^{-\frac{r}{2x}\varphi}\left\{\sin\omega\cos\sqrt{\frac{k}{x}}\,\varphi-\left[\sqrt{\frac{k}{x}}\cos\omega\right.\right.\right. \\ &\qquad\left.\left.\left.+\frac{r}{2\sqrt{xk}}\sin\omega\right]\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \\ e_1'' &= -E\,\varepsilon^{-\frac{r}{2x}\varphi}\left\{\cos\omega\cos\sqrt{\frac{k}{x}}\,\varphi+\left[\frac{r}{2\sqrt{xk}}\cos\omega\right.\right. \\ &\qquad\left.\left.+\frac{r^2+4xk}{4k\sqrt{xk}}\sin\omega\right]\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \end{aligned}\right\} \tag{22}$$

or, by dropping terms of secondary order:

$$\left.\begin{aligned} i'' &= \frac{E}{\sqrt{xk}}\,\varepsilon^{-\frac{r}{2x}\varphi}\cos\omega\sin\sqrt{\frac{k}{x}}\,\varphi \\ e_1'' &= -E\,\varepsilon^{-\frac{r}{2x}\varphi}\cos\omega\cos\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\} \tag{23}$$

$$\left.\begin{aligned} i''' &= \varepsilon^{-\frac{r}{2x}\varphi}\left\{i_0\cos\sqrt{\frac{k}{x}}\,\varphi-\frac{2e_0+ri_0}{2\sqrt{xk}}\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \\ e_1''' &= \varepsilon^{-\frac{r}{2x}\varphi}\left\{e_0\cos\sqrt{\frac{k}{x}}\,\varphi+\frac{2re_0+(r^2+4xk)i_0}{4\sqrt{xk}}\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \end{aligned}\right\} \tag{24}$$

or, by dropping terms of secondary order:

$$\left.\begin{aligned} i''' &= \varepsilon^{-\frac{r}{2x}\varphi}\left\{i_0\cos\sqrt{\frac{k}{x}}\,\varphi-\frac{e_0}{\sqrt{xk}}\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \\ e_1''' &= \varepsilon^{-\frac{r}{2x}\varphi}\left\{e_0\cos\sqrt{\frac{k}{x}}\,\varphi+i_0\sqrt{xk}\sin\sqrt{\frac{k}{x}}\right\} \end{aligned}\right\} \tag{25}$$

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Thus:

Total Current, approx:

$$\left.\begin{aligned} i = &-\frac{E}{k}\sin(\varphi-\omega)+\varepsilon^{-\frac{r}{2x}\varphi}\left\{ i_0\cos\sqrt{\frac{k}{x}}\,\varphi \right. \\ &\left. -\frac{e_0-E\cos\omega}{\sqrt{x\,k}}\sin\sqrt{\frac{k}{x}}\,\varphi \right\} \end{aligned}\right\}$$

Difference of Potential at Condenser:

$$\left.\begin{aligned} e_1 = &E\cos(\varphi-\omega)+\varepsilon^{-\frac{r}{2x}\varphi}\left\{ (e_0-E\cos\omega)\cos\sqrt{\frac{k}{x}}\,\varphi \right. \\ &\left. +i_0\sqrt{x\,k}\sin\sqrt{\frac{k}{x}}\,\varphi \right\} \end{aligned}\right\} \quad (26)$$

Of the three terms: i', e_1'; i'', e_1''; i''', e_1''', the first obviously represents the stationary condition of charging current and condenser potential, since the two other terms disappear for $t=\infty$.

The second term, i'', e_1'', represents that component of oscillation which depends upon the phase of impressed E. M. F., or the point of the impressed E. M. F. wave, at which the oscillation begins, while the third term, i''', e_1''', represents the component of oscillation which depends upon the instantaneous values of current resp. E. M. F. at the moment at which the oscillation begins. $\varepsilon^{-(r/2x)\varphi}$ is the decrement of the oscillation.

The frequency of oscillation is:

$$N_0=\sqrt{\frac{k}{x}}\,N$$

where N is the impressed frequency. That is, the frequency of oscillation equals the impressed frequency times the square root of the ratio of capacity reactance and inductive reactance of the circuit, or is the impressed frequency divided by the square root of inductance voltage and capacity current, as fraction of impressed voltage and full load current.

Since:

$$k=\frac{1}{2\pi N C},\quad x=2\pi N L,$$

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the frequency of oscillation is:

$$N_0 = \frac{1}{2\pi\sqrt{CL}}$$

that is, independent of the frequency of the impressed E. M. F.

Substituting:

$$\varphi = 2\pi N t,\ k = \frac{1}{2\pi N C},\ x = 2\pi N L$$

in equations (23), (25), and (26), it is:

$$\left.\begin{aligned} i'' &= \sqrt{\frac{C}{L}}\, E\, \varepsilon^{-(r/2L)t} \cos\omega \sin\frac{t}{\sqrt{CL}} \\ e_1'' &= -E\,\varepsilon^{-(r/2L)t} \cos\omega \cos\frac{t}{\sqrt{CL}} \end{aligned}\right\} \quad (27)$$

$$\left.\begin{aligned} i''' &= \varepsilon^{-(r/2L)t}\left\{ i_0 \cos\frac{t}{\sqrt{CL}} - e_0\sqrt{\frac{C}{L}}\sin\frac{t}{\sqrt{CL}}\right\} \\ e_1''' &= \varepsilon^{-(r/2L)t}\left\{ e_0 \cos\frac{t}{\sqrt{CL}} + i_0\sqrt{\frac{L}{C}}\sin\frac{t}{\sqrt{CL}}\right\} \end{aligned}\right\} \quad (28)$$

$$\left.\begin{aligned} i &= -2\pi N C E' \sin(\varphi-\omega) + \varepsilon^{-(r/2L)t}\left\{ i_0\cos\frac{t}{\sqrt{CL}} \right. \\ &\qquad \left. -(e_0 - E\cos\omega)\sqrt{\frac{C}{L}}\sin\frac{t}{\sqrt{CL}}\right\} \\ e_1 &= E\cos(\varphi-\omega) + \varepsilon^{-(r/2L)t}\left\{ (e_0 - E\cos\omega)\cos\frac{t}{\sqrt{CL}} \right. \\ &\qquad \left. + i_0\sqrt{\frac{L}{C}}\sin\frac{t}{\sqrt{CL}}\right\} \end{aligned}\right\} \quad (29)$$

The oscillating terms of these equations is independent of the impressed frequency. That is, the oscillating current and potential difference, caused by a change of circuit conditions (as starting, change of load or opening circuit), are independent of the impressed frequency, and thus also of the wave shape of the im-

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pressed E. M. F., or its higher harmonics (except as regards to terms of secondary order).

The first component of oscillation, equations (22) and (23), besides upon the line constants and upon the impressed E. M. F., depends only upon the phase, or the point of the impressed E. M. F. wave, at which the oscillation starts, but does not depend upon the previous condition of the circuit.

Therefore this component of oscillation is the same as the oscillation produced in starting the transmission line, that is, connecting it, unexcited, to the generator terminals.

There exists no point of the impressed E. M. F. wave, where no oscillation occurs (while, when starting a circuit containing resistance and induction only, at the point of the impressed E. M. F. wave, where the final current passes zero, the stationary condition is instantly reached).

With capacity in circuit, any change of circuit conditions involves an electric oscillation.

The maximum intensity of starting oscillation occurs near the value: $a=o$, and is:

$$\left.\begin{aligned} i'' &= \frac{E}{\sqrt{x\,k}}\,\varepsilon^{-(r/2x)\varphi}\sin\sqrt{\frac{k}{x}}\,\varphi \\ e_1'' &= -E\,\varepsilon^{-(r/2x)\varphi}\cos\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\} \quad (30)$$

Since:

$$i' = -\frac{E}{k}\sin(\varphi - \omega)$$

is the stationary value of charging current, it follows:

The maximum intensity which the oscillating current produced in starting a transmission line may reach, is $\sqrt{\frac{k}{x}}$ times the stationary charging current, or the initial rush of current bears to the stationary value the same ratio as the frequency of oscillation to the impressed frequency.

The maximum oscillating E. M. F. induced in starting a transmission line is of the same value as the impressed E. M. F. Thus the maximum value of potential difference occurring in a transmission line at starting is less than twice the impressed E. M. F. and no excessive voltages can be induced in starting a circuit.

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The minimum value of starting oscillation occurs near: $\omega=90°$, and is, from equations (22):

$$\left.\begin{aligned} i'' &= -\frac{E}{k}\,\epsilon^{-(r/2x)\varphi}\cos\sqrt{\frac{k}{x}}\,\varphi \\ e_1'' &= \sqrt{\frac{x}{k}}\,E\,\epsilon^{-(r/2x)\varphi}\sin\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\} \quad (31)$$

That is, the oscillating current is of the same intensity as the charging current, and the maximum rush of current thus is less than twice the stationary value. The potential difference in the circuit rises only little above the impressed E. M. F.

The second component of oscillation, equations (24.) (25.), does not depend upon the point of the impressed E. M. F. wave, at which the oscillation starts, ω, nor upon the impressed E. M. F. as a whole, E, but, besides upon the constants of the circuit, it only depends upon the instantaneous values of current and of potential difference in the circuit at the moment where the oscillation starts, i_0 and e_0.

Thus, if: $i_0 = 0$, $e_0 = 0$, or in starting a transmission line, unexcited, by connecting it to the impressed E. M. F., this term disappears.

It is this component which may cause excessive potential differences.

Two cases shall more fully be discussed.

(*a*.) Opening the circuit of a transmission line under load.

(*b*.) Rupturing a short-circuit on the transmission line.

A.

If i_0 is the instantaneous value of full load current, e_0 the instantaneous value of difference of potential at the condenser, it is:

ri small compared with e_0:

$\sqrt{x\,k}\,i_0$ of the same magnitude as e_0.

Denoting:

$$\tan\delta = \frac{e_0}{i_0\sqrt{x\,k}}$$

it is, substituting in equations (24):

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$$\left.\begin{aligned} i''' &= \sqrt{i_0^2 + \frac{e_0^2}{x\,k}}\;\varepsilon^{-(r/2x)\varphi}\cos\left(\sqrt{\frac{k}{x}}\,\varphi + \delta\right) \\ e_1''' &= \sqrt{e_0^2 + i_0^2\,x\,k}\;\varepsilon^{-(r/2x)\phi}\sin\left(\sqrt{\frac{k}{x}}\,\varphi + \delta\right) \end{aligned}\right\} \quad (32)$$

That is, the amplitude of oscillation is

$$\sqrt{i_0^2 + \frac{e_0^2}{x\,k}}$$

for the current, $\sqrt{e_0^2 + i_0^2\,x\,k}$ for the E. M. F. Thus the induced E. M. F. can be larger than the impressed E. M. F., but is, as a rule, still of the same magnitude, except if k is very large.

In the expression of the total current resp. potential difference at condenser, in equations (26.), $(e_0 - E\cos\omega)$ is the difference between the potential difference at the condenser and the impressed E. M. F., at the instant of starting of the oscillation, or the voltage consumed by the line impedance, and this is small, if the current is not excessive. Thus, neglecting the terms with $(e_0 - E\cos\omega)$, equations (26.) assume the form:

$$\left.\begin{aligned} i &= -\frac{E}{k}\sin(\varphi - \omega) + i_0\,\varepsilon^{-(r/2x)\phi}\cos\sqrt{\frac{k}{x}}\,\varphi \\ e_1 &= E\cos(\varphi - \omega) + i_0\sqrt{x\,k}\;\varepsilon^{-(r/2x)\phi}\sin\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\} \quad (33)$$

That is, the oscillation of current is of the amplitude of full load current, and the oscillation of condenser potential is of the amplitude $i_0\sqrt{x\,k}$.

$x\,k$ is the ratio of inductance voltage to condenser current, in fractions of full load voltage and current. It is also:

$$i_0\sqrt{xk} = i_0\sqrt{\frac{L}{C}}$$

Thus in circuits of very high inductance L and relatively low capacity C, $i_0\sqrt{x\,k}$ may be much higher than the impressed E. M. F., and a serious rise of potential occur in opening the circuit under load, while in low inductance cables of high capacity,

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$i_0 \sqrt{x\,k}$ is moderate. That is, the inductance, by tending to maintain the current, induces a rise of potential, while capacity exerts a cushioning effect. Low inductance and high capacity thus are of advantage when breaking full load current in a circuit.

B.

If a transmission line containing resistance, inductance and capacity is short-circuited, and the short-circuit suddenly opened at time $t = 0$, it is, for: $t < 0$:

$$\left.\begin{aligned} e_0 &= 0 \\ i &= \frac{E}{z}\cos(\varphi - \omega - j) \\ \text{where:} \qquad z &= \sqrt{r^2 + x^2} \\ \tan j &= \frac{x}{r} \end{aligned}\right\} \quad (34)$$

thus, at time: $t = 0$

$$i_0 = \frac{E}{z}\cos(\omega + j) \qquad (35)$$

Substituting these values of e_0 and i_0 in equations (24), gives:

$$i''' = \frac{E}{z}\cos(\omega+j\,\varepsilon^{-(r/2x)\phi}\left\{\cos\sqrt{\frac{k}{x}}\varphi - \frac{r}{2\sqrt{x\,k}}\sin\sqrt{\frac{k}{x}}\varphi\right\}$$

$$e_1''' = \frac{E}{z}\cos(\omega + j)\,\varepsilon^{-(r/2x)\phi}\,\frac{r^2 + 4\,x\,k}{4\sqrt{x\,k}}\sin\sqrt{\frac{k}{x}}\varphi$$

or, neglecting terms of secondary magnitude:

$$\left.\begin{aligned} i''' &= \frac{E}{z}\,\varepsilon^{-(r/2x)\phi}\cos(\omega + j)\cos\sqrt{\frac{k}{x}}\varphi \\ e_1''' &= \frac{E\sqrt{x\,k}}{z}\,\varepsilon^{-(r/2x)\phi}\cos(\omega + j)\sin\sqrt{\frac{k}{x}}\varphi \end{aligned}\right\} \quad (36)$$

That is, i''' is of the magnitude of short-circuit current, and e_1''' of higher magnitude than the impressed E. M. F., since z is small compared with $\sqrt{x\,k}$.

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The total values of current and condenser potential difference are, from equation (26):

$$\left.\begin{aligned} i &= -\frac{E}{k}\sin(\varphi-\omega)+E\,\varepsilon^{-(r/2x)\phi}\left\{\left[\frac{\cos(\omega+j)}{z}\right.\right.\\ &\qquad\left.\left.-\frac{\sin\omega}{k}\right]\cos\sqrt{\frac{k}{x}}\,\varphi+\frac{\cos\omega}{\sqrt{xk}}\sin\sqrt{\frac{k}{x}}\,\varphi\right\}\\ e_1''' &= E\cos(\varphi-\omega)-E\,\varepsilon^{-(r/2x)\phi}\left\{\cos\omega\cos\sqrt{\frac{k}{x}}\,\varphi\right.\\ &\qquad\left.-\frac{\sqrt{xk}\cos(\omega+j)}{z}\sin\sqrt{\frac{k}{x}}\,\varphi\right\} \end{aligned}\right\}\quad(37)$$

or approximately, since all terms are negligible compared with i''' and e_1''':

$$\left.\begin{aligned} i &= \frac{E}{z}\,\varepsilon^{-(r/2x)\phi}\cos(\omega+j)\cos\sqrt{\frac{k}{x}}\,\varphi\\ e_1 &= \frac{E\sqrt{xk}}{z}\,\varepsilon^{-(r/2x)\phi}\cos(\omega+j)\sin\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\}\quad(38)$$

These values are a maximum, if the circuit is opened at the moment: $a=-j$, that is at the maximum value of the short-circuit current, and are then:

$$\left.\begin{aligned} i &= \frac{E}{z}\,\varepsilon^{-(r/2x)\phi}\cos\sqrt{\frac{k}{x}}\,\varphi\\ e_1 &= \frac{\sqrt{xk}}{z}\,E\,\varepsilon^{-(r/2x)\phi}\sin\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\}\quad(39)$$

The amplitude of oscillation of condenser potential difference is:

$$\frac{\sqrt{xk}}{z}E$$

or, neglecting the line resistance, as rough approximation: $x=z$:

$$\sqrt{\frac{k}{x}}\,E$$

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That is, the potential difference at the condenser is increased above the impressed E. M. F. in the proportion of the square root of the ratio of capacity reactance to inductive reactance, or inverse proportional to the square root of inductance voltage times capacity current, as fraction of impressed voltage and full load current.

Thus in this case, the rise of voltage is excessive.

The minimum intensity of the oscillation due to rupturing short-circuit occurs if the circuit is broken at the moment: $a = 90° - j$, that is, at the zero value of short-circuit current. It is then:

$$\left.\begin{aligned} i &= \frac{E}{\varphi}\cos(\varphi + j) - E\,\varepsilon^{-(r/2x)\varphi}\left\{\frac{\cos j}{\varphi}\cos\sqrt{\frac{\varphi}{x}}\,\varphi\right. \\ &\qquad \left. - \frac{\sin j}{\sqrt{x\varphi}}\sin\sqrt{\frac{\varphi}{x}}\,\varphi\right\} \\ e_1 &= E\sin(\varphi + j) - E\,\varepsilon^{-(r/2x)\varphi}\sin j\cos\sqrt{\frac{k}{x}}\,\varphi \end{aligned}\right\} \quad (40)$$

That is, the potential difference at the condenser is less than twice the impressed E. M. F., thus moderate.

Hence, a short-circuit can be opened safely only at or near the zero value of the short-circuit current.

The phenomenon ceases to be oscillating, and becomes an ordinary logarithmic discharge, if $\sqrt{r_2 - 4\,x\,k}$ is real, or:

$$r < 2\sqrt{x\,\varphi}.$$

Some instances may illustrate the phenomena discussed in the preceding:

I.

Let in a transmission line carrying 100 amperes at full load, under an impressed E. M. F. of 20,000 volts, the resistance drop equal 8%, the inductance voltage 15% of the impressed voltage, and the charging current 8% of full load current. Assuming as resistance drop in the step-up transformers, 1%, and as reactance voltage 2½%.

The resistance drop between constant potential generator terminals and middle of transmission line is then 5%, or $r = 10$ ohms. The inductance voltage is 10%, or $x = 20$ ohms. The

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charging current of the line is 8 amperes, thus the capacity reactance $k = 2500$ ohms.

It is then, assuming a sine wave of impressed E. M. F.:

$$E = 20000\sqrt{2} = 28280 \text{ volts.}$$

$$i' = -11.3 \sin(\varphi - \omega)$$
$$e_1' = 28280 \cos(\varphi - \omega)$$

$$i'' = -11.3\,\varepsilon^{-.25\phi}[\sin\omega\cos 11.2\varphi - 11.2\cos\omega\sin 11.2\varphi]$$
$$e_1'' = -28280\,\varepsilon^{-.25\phi}[\cos\omega\cos 11.2\varphi - .089\sin\omega\sin 11.2\varphi]$$

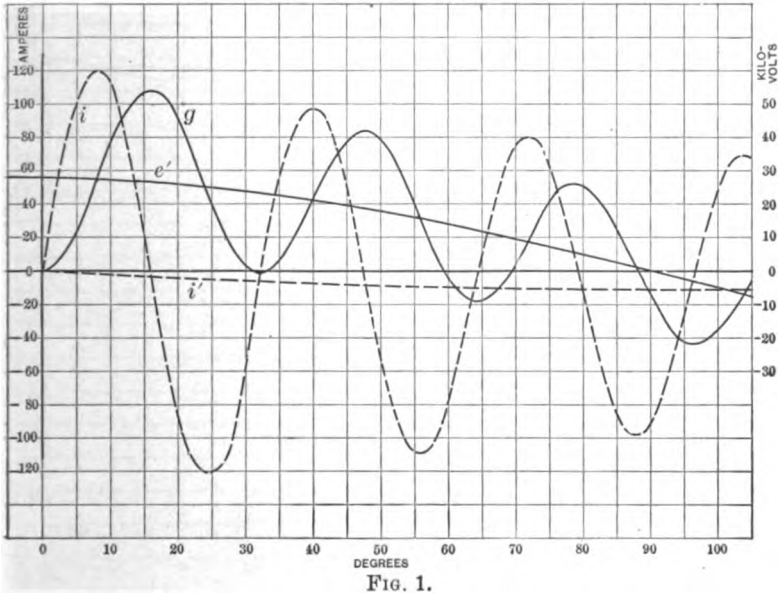

FIG. 1.

Thus, the oscillation produced in starting the transmission line is:

$$i = -11.3\,[\sin(\varphi - \omega) + \varepsilon^{-.25\phi}(\sin\omega\cos 11.2\varphi - 11.2\cos\omega\sin 11.2\varphi)]$$
$$e_1 = 28280\,[\cos(\varphi - \omega) - \varepsilon^{-.25\phi}(\cos\omega\cos 11.2\varphi - .089\sin\omega\sin 11.2\varphi)]$$

Hence the maximum value, for: $\omega = 0$:

$$i = -11.3\,(\sin\varphi - 11.2\,\varepsilon^{-.25\phi}\sin 11.2\varphi)$$
$$e_1 = 28280\,(\cos\varphi - \varepsilon^{-.25\phi}\cos 11.2\varphi)$$

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and the minimum value, for: $\omega = 90°$:

$$i = 11.3\ (\cos \varphi - \varepsilon^{-.25\,\varphi} \cos 11.2\ \varphi)$$
$$e_1 = 28280\ (\sin \varphi + .089\ \varepsilon^{-.25\,\varphi} \sin 11.2\ \varphi)$$

These values are plotted in Figs. 1 and 2, with the current i in dotted and the potential difference e_1 in drawn line. The stationary values are plotted also, in thin lines.

(a.) Opening the circuit under full load, it is:

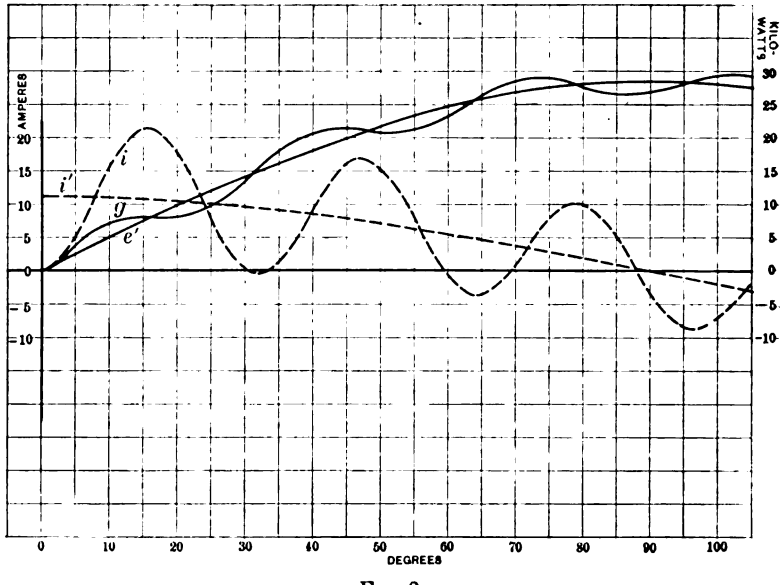

FIG. 2.

$$i = -11.3 \sin (\varphi - \omega) + \varepsilon^{-.25\,\varphi} (i_o - 11.3 \sin \omega) \cos 11.2\ \varphi$$
$$e_1 = -28280 \cos (\varphi - \omega) + 224\ i_o\ \varepsilon^{-.25\,\varphi} \sin 11.2\ \varphi$$

These values are maximum for $\omega = 0$ and non-inductive circuit, or: $i_o = 141.4$, and are:

$$i = -11.3 \sin \varphi + 141.4\ \varepsilon^{-.25\,\varphi} \cos 11.2\ \varphi$$
$$e_1 = 28280 \cos \varphi + 31600\ \varepsilon^{-.25\,\varphi} \sin 11.2\ \varphi$$

These values are plotted, in Fig. 3, in the same manner as Figs. 1 and 2:

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(*b*.) Rupturing the line under short-circuit, it is:

$$z = 22.4$$
$$i_0 = 1265 \cos (\omega + j$$

thus:

$$i = -11.3 \sin (\varphi - \omega) + 1265\, \varepsilon^{-.25\,\phi} \{[\cos (\omega + j) - .0089 \sin \omega] \cos 11.2\, \varphi + .1 \cos \omega \sin 11.2\, \varphi\}$$
$$e_1 = 28280 \{\cos (\varphi + \omega) - \varepsilon^{-.25\,\phi} [\cos \omega \cos 11.2\, \varphi - 10 \cos (\omega + j) \sin 11.2 \varphi]\}$$

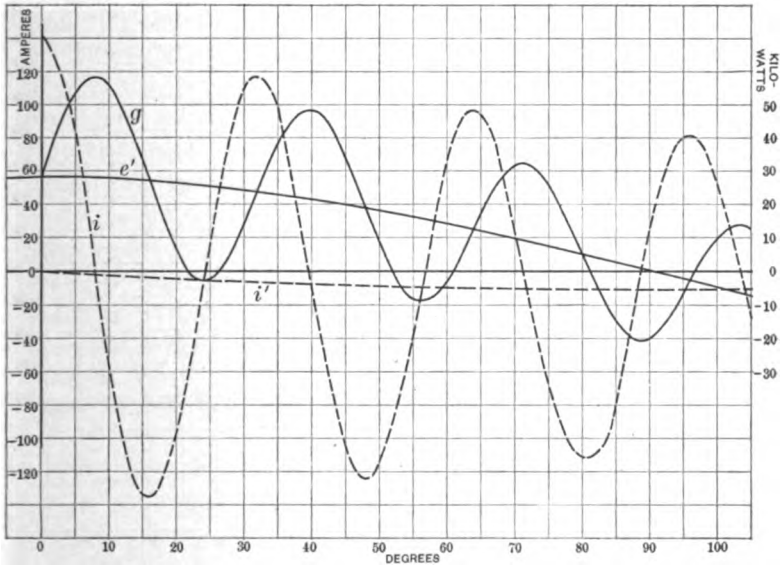

FIG. 3.

These values are a maximum for: $\omega = -j = -63°$:

$$i = -11.3 \sin (\varphi + 63°) + 1260\, \varepsilon^{-.25\,\phi} (\cos 11.2\, \varphi + .044 \sin 11.2\, \varphi)$$
$$e_1 = 28280 \cos (\varphi + 63°) - 282{,}800\, \varepsilon^{-.25\,\phi} (.044 \cos 11.2\, \varphi - \sin 11.2\, \varphi)$$

That is, the potential difference rises about tenfold, to 282,800 volts.

These values are plotted in Fig. 4.

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II.

In the instance referred to in the beginning of the paper, where I first observed the destructive voltage induced by a short-circuiting arc, on an experimental 10,000-volt 40-cycle line, during the occurrence of the phenomenon the generator voltage probably fell to about 5,000, due to limited capacity. The resistance of the system was very low, about $r = 1$ ohm, while the inductive reactance may be estimated as $x = 10$ ohms, and the capacity reactance as $k = 20{,}000$ ohms.

It is thus: $\tan j = 10$, or approximately: $j = 90°$.

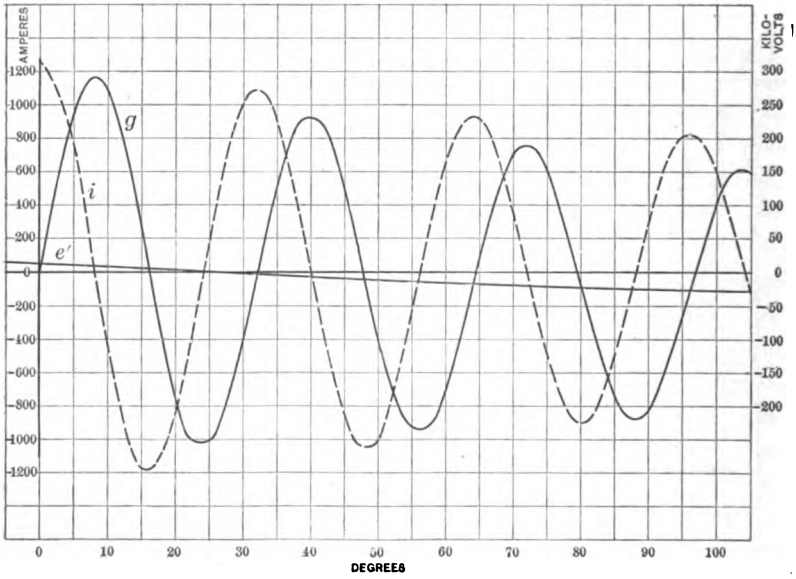

FIG. 4.

Herefrom it follows:

$$i = 707\ \varepsilon^{-.05\,\phi} \cos 44.7\ \varphi$$

$$e_1 = 316000\ \varepsilon^{-.05\,\phi} \sin 44.7\ \varphi$$

That is, the oscillation has a frequency of about 1,800 cycles, and a maximum E. M. F. of nearly one-third million volts, which fully accounts for its disruptive effects.

As conclusion, it follows herefrom:

1. The most important source of destructive high voltage phenomena in high potential circuits containing inductance and capacity are not resonance phenomena with the wave of im-

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pressed E. M. F. or its higher harmonics, in case of the deviation of the wave from sine shape, but are the electric oscillations produced by a change of circuit conditions, as starting, opening circuit, etc.

2. These phenomena are essentially independent of frequency and wave shape of impressed E. M. F., but depend upon the conditions under which the circuit is changed, as the manner of change and the point of the impressed E. M. F. and current wave at which the change occurs.

3. The electric oscillations occuring in connecting a transmission line to the generator are not of dangerous potential, but the oscillations produced by opening the transmission circuit under load may reach destructive voltages, and the oscillations caused by interrupting a short-circuit are liable to reach voltages far beyond the strength of any insulation. Thus special precautions should be taken in opening a high potential circuit under load. But the most dangerous phenomenon is a low resistance short-circuit in open space.

4. The voltages produced by the oscillations in open-circuiting a transmission line under load or under short-circuit are moderate, if the opening of the circuit occurs at a certain point of the E. M. F. wave. This point approximately coincides with the moment of zero current.

March, 1901.
Schenectady, N. Y.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22nd, 1901, Vice-President Dunn in the Chair.

THE CONTROL OF HIGH POTENTIAL SYSTEMS OF LARGE POWER.

BY E. W. RICE, JR.

The enormous increase in the use of electricity for lighting, traction and power has necessitated important changes in our generating stations. As the areas to be served have rapidly increased, corresponding increases have been made in the size of these stations and in the electrical potentials employed. The change has been due, not only to the great natural growth but to the consolidation of generating machinery into fewer stations. Instead of a number of separate stations, containing relatively small units producing electricity at comparatively low voltage with relatively large transmission losses, we now frequently find one large central station, containing generating units of great size delivering electricity at a high potential. Dynamos of 2,000 to 5,000 kilowatts capacity are displacing those of 200 to 500 kilowatts, and pressures of 5,000 to 15,000 volts those of 1,000 to 2,000 volts. The design and manufacture of large generating units of this character have called for engineering skill of a high order, and it can now be fairly claimed that the production of such machines has been reduced to an exact science.

The rapid evolution and present perfection in dynamo design have been due to the skill with which the various problems have been solved by the designing engineers and to the ease with which the data based upon machines of relatively small size were applied to those of larger size.

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It is evident, however, that great advances in the capacity and voltage of generators would be useless, if not positively dangerous, unless adequate means for controlling and switching the electrical current were at hand. The evolution of the dynamo was for a time more rapid than that of the devices for controlling and switching currents of large volume and potential. As a result, a number of machines of large size were placed in operation with comparatively inadequate methods of switching and controlling. The energy and power which can be safely concentrated in a single central station is obviously limited by the amount of current and voltage which switching devices can safely handle. This fact was especially forced upon the attention of the writer at the time when the company with which he is connected took the contract for the equipment of the generating station of the Metropolitan Traction Company of New York. This station was to contain eleven three-phase dynamos, each of 3,500 kilowatts output at 6,600 volts. In order to realize the full economy of such a station, it was, of course, necessary that all the generators should supply current to a common bus bar, and that from these bus bars the current should be distributed through feeders to a number of sub-stations. The sub-stations were to contain rotary converters, frequently working in multiple with large storage batteries on the direct current side. The characteristics of such a load prevented any reliance being placed upon the opening of the exciting circuit of the generators in case of the necessity of a general shut-down, as the rotary converters would, under certain conditions, supply sufficient magnetizing current to excite the generators, even with the field windings of the generators unexcited. It became, therefore, essential to produce a switching mechanism which would enable the generators to be connected and disconnected from the bus-bars with certainty and safety under all conditions of load, even up to a short-circuit, and also that the various feeders supplying the sub-stations should be capable of the same treatment. Three types of switching devices were available for this work and were carefully considered :

1. Switches breaking the circuit in the open air.

3. Switches arranged to break the circuit in an enclosed air space.

3. Switches arranged to break the circuit under oil.

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Switches of the first type (open air) were impracticable, because the space demanded to make such switches operative could not be provided.

Switches of the second type (enclosed air) had no such limitation, but oil-break switches were found to meet the conditions more perfectly. Tests conducted showed that energy up to 2,000 or 3,000 kilowatts could be controlled in a single oil switch at potentials as high as 15,000 volts, which was the limit of the apparatus at our disposal at the time. Switches of this type, however, as large as was considered necessary, required an amount of oil per switch so great as to be objectionable, in view of the large number of switches required for generators and feeders. The problem then was to produce a switch which would retain all the advantages of the usual oil switch and at the same time minimize the quantity of oil.

The type which was finally evolved and employed in the Metropolitan installation has shown itself in practice to be remarkably successful. It is known as the Form "H" Oil Switch by the manufacturers, and was designed by the writer, with the assistance of Mr. E. M. Hewlett. It was described by Mr. J. E. Woodbridge in the *Electrical World and Engineer* of April 14th, 1900. Reference to this article will give the details, which I need not here repeat; I shall simply outline the principal features.

The switch, as designed for three-phase circuits, consists of three double-pole, single-phase switches, or elements. Each single-phase switch is contained in a fireproof cell, but all three switches are designed to be operated simultaneously. Each single-phase element consists of two brass cylinders or cans, one can for each pole. The in-coming lead is attached to one of the cans and the out-going lead of the same phase to the other. Each cylinder is nearly filled with oil and is covered by a metal cap which carries a long insulating sleeve. Two copper rods joined by a metallic cross-head and forming together a U-shaped conductor, slide through the insulating sleeve and fit into tubular contacts at the bottom of the cans when closing the circuit. The cross-head of each U-shaped conductor is attached to a wooden rod, which extends through the top of the cell or casing which encloses the switch, and is in turn attached to a metal cross-head operated by an air motor or an electric motor, as the case may be. The three phases are seen, therefore, to be broken or closed simultaneously. When the three sets of U-shaped

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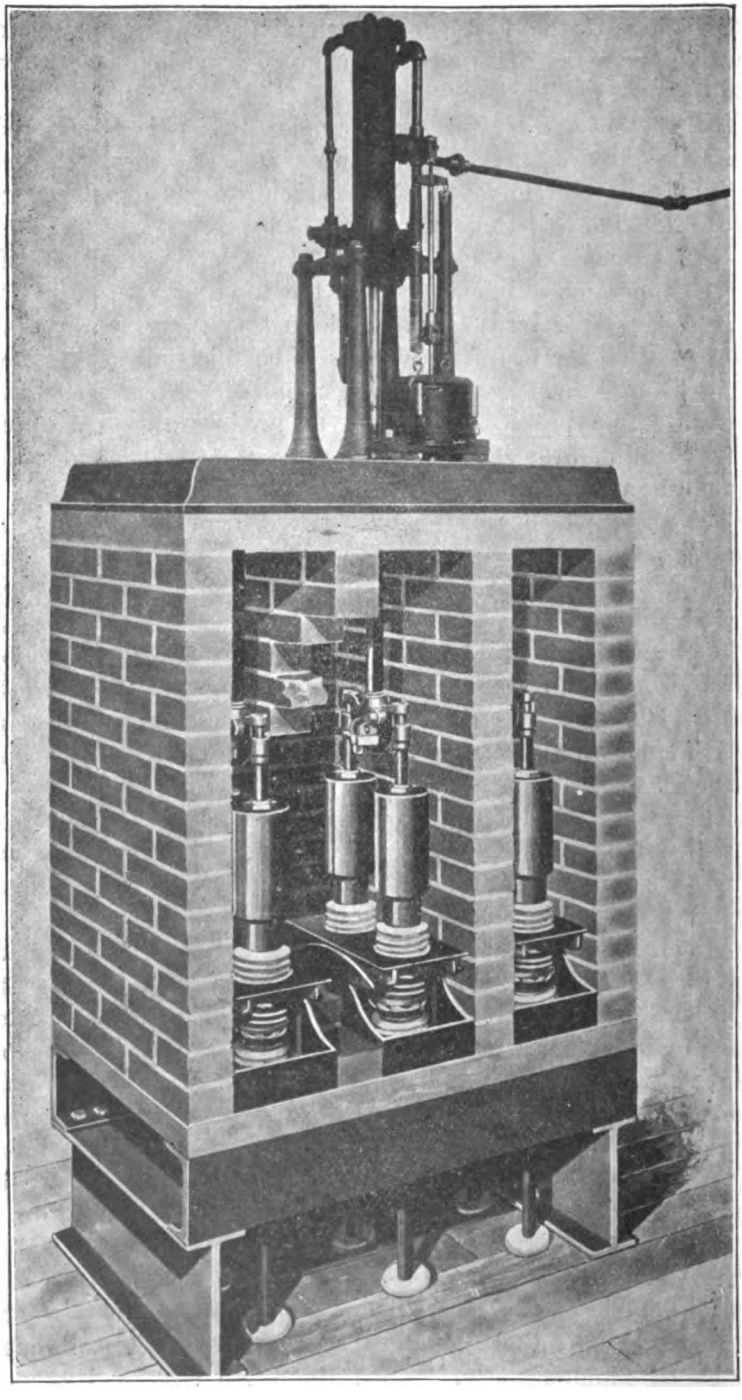

Fig. 1.—Pneumatically Operated Type H Switch, Metropolitan Traction Company's Station.

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conductors are lifted, the circuit is broken under the oil at two points in each phase, or six points in each complete three-phase switch. The range of movement of the cross-head varies with

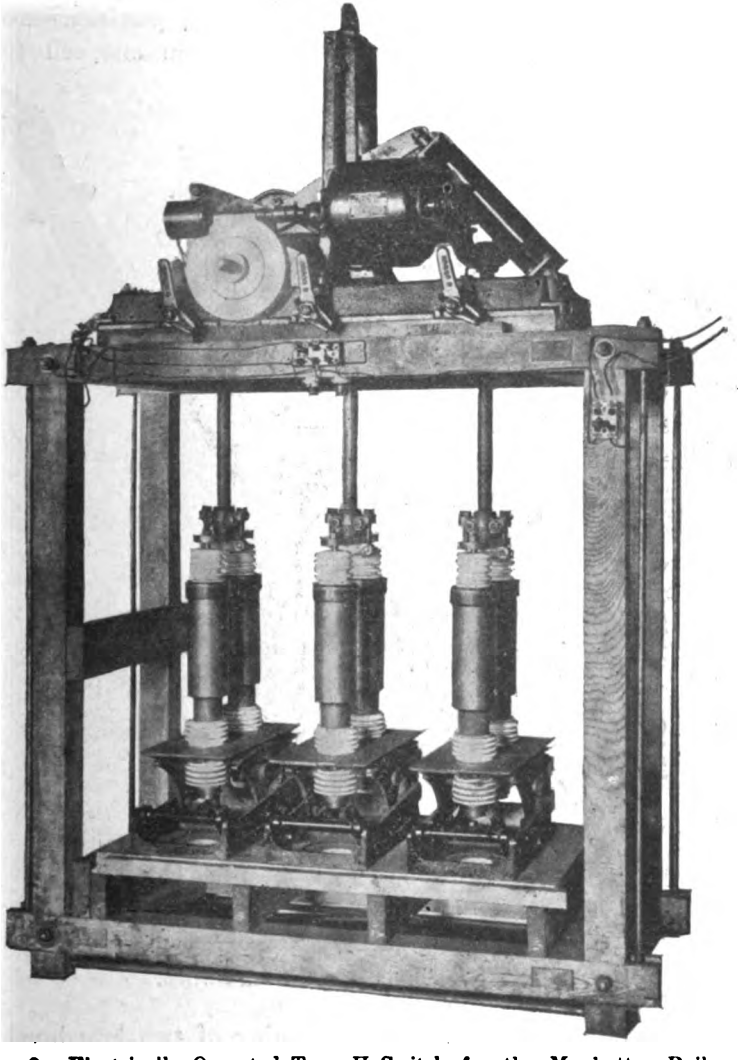

Fig. 2.—Electrically Operated Type H Switch for the Manhattan Railway Company, with brick partition removed.

the potential to be controlled, *e. g.*, it is 12 inches in the switches in the Metropolitan station for 6000 volts, and 17 inches in the switches for the Manhattan station for 12,000 volts. The brass

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cans are lined internally with fiber to prevent the arc from jumping from the rod to the metal of the can when it is drawn up through the oil. Each switch unit stands alone on its own foundation, with the three phases in three separate cells or spaces separated by brick walls. These brick partitions act as barriers and prevent any possible burn-out in one cell from

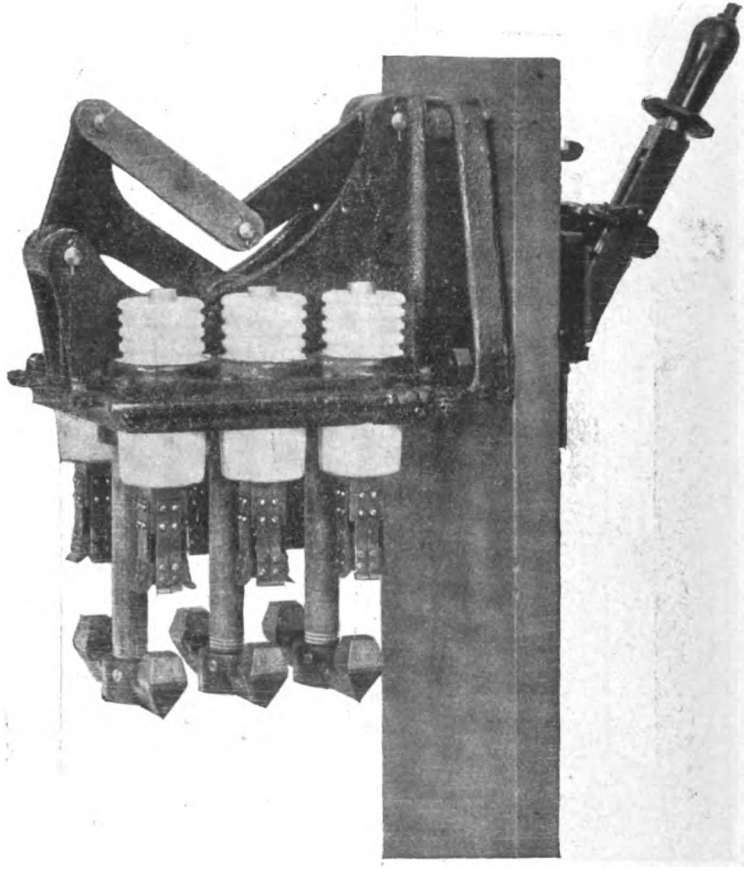

Fig. 3.—Form FK Oil Break Switch.

spreading to the others. As an opening of two legs breaks a three-phase line, an arc in one cell will not incapacitate the switch. The circuit breaker or switch differs radically from older forms in the separation of the phases as indicated, and also in the separation of the contacts for each phase, in two separate oil pots. This separation of the terminals of each phase gives two separate arcs, each enclosed in a space well removed from

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the others, so that the possibility of an arc communicating from one pole to another is obviated. It will be seen that in breaking a three-phase circuit, the arc is produced in six independent oil pots. This method of construction, together with the separation of the phases in separate fireproof compartments, accounts for the unusual effectiveness of the switch in practical operation. The general construction of the switch is clearly shown in the accompanying illustration.

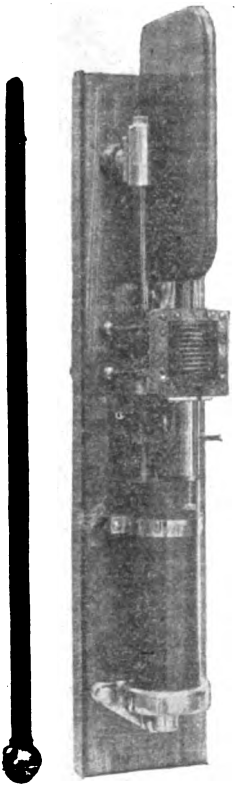

FIG. 4.—Expulsion type switch.

Fig. 1 shows the switch used in the installation of the Metropolitan Traction Co., New York. It is designed for 6600 volts and 300 to 800 amperes.

Fig. 2 shows the same switch as modified to suit the conditions of the Manhattan electric installation. On account of the higher voltage the oil pots are larger and a larger opening of the circuit is provided. The twelve covers for the oil pots are replaced by porcelain. It is designed for 12,000 volts and 300,800 amperes.

Fig. 3 illustrates the enclosed air tube type of switch already mentioned. This switch has given most excellent results on high potential work.

Fig. 4 shows the form FK, or tank oil switch, without tank for containing oil.

Fig. 5 is a reproduction from a photo taken at Kalamazoo of a special form of open air switch. The switch was opening a circuit of 25,000 volts and 60 amperes at the time when the photograph was taken.

It was at first thought that the use of oil switches for the control of high potential circuits would possibly result in resonance effects, particularly in circuits containing considerable capacity, such as underground cables or long overhead lines. A number of experiments have been conducted and the weight of evidence seems to be in favor of the oil switch as avoiding these

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effects. It has been found as an interesting fact that under the conditions described considerable disturbance due to resonance may occur upon the *closing* of a circuit. This is naturally independent of the character of the switch employed; it may

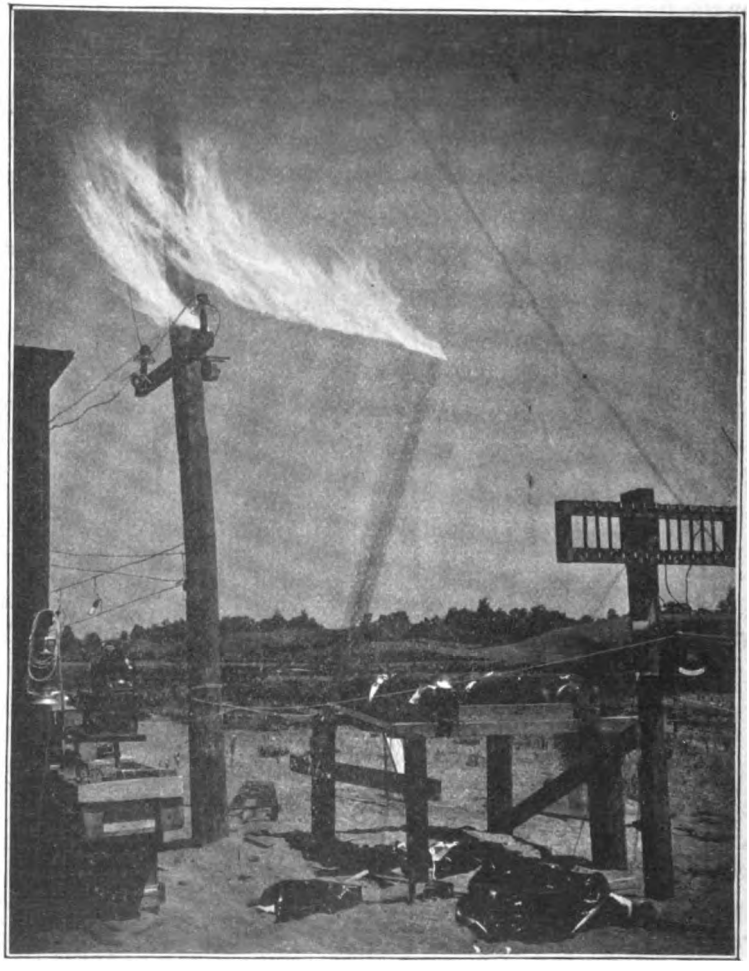

Fig. 5.—Air Break Switch (Kalamazoo Test).

occur equally well with an oil, an enclosed air, or an open air switch.

Upon the rupture of the circuit, however, the results obtained from many tests indicate that open air switches are liable to produce heavy resonance effects while the enclosed air

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and the oil switch are practically free from such effects. Extensive experiments to determine this point were conducted prior to the production of the switches for the Metropolitan and Manhattan stations. Very recently experiments of a more severe character have been conducted at Kalamazoo, Mich. These tests were made at from 25,000 to 40,000 volts with from 1,200 to 1,300 K. V. A. of highly inductive load, the power factor being from 40 to 60 per cent. The switches tested were the cylindrical oil switch, already described (Metropolitan type); an oil switch in which all the terminals were enclosed in a single tank of oil, called the tank oil switch, type "K"; a switch of the expulsion air tube type; and an open air switch in which the terminals were simply separated long distances in free air. In making these tests an oscillagraph was used to determine the time of break and other interesting effects, and a camera to photograph any particular instructive phenomena.

The long break open air switch, which operates upon the principle of drawing a long arc in the open air, opened the circuit at 25,000 volts, but required several seconds of time and drew such a long arc as to be impracticable. At 40,000 volts the arc held and flared to a total distance of over 30 feet until it struck the line and short-circuited the system, producing at the same time high-voltage oscillations equal to two or three times the normal potential of the system. It would therefore seem that the open air switch was generally unsuitable for the control of high-voltage systems of large powers, as even where sufficient room is available for their use, the production of high resonance effects tends to endanger the system. These tests also show that wherever a short-circuiting arc occurred in the open air, electric oscillations of high voltage resulted. These were probably due to the rapid alternate extinguishment and formation of the arc during its period of interruption, the arc acting somewhat in the manner of a Wehnelt interrupting device. The dangerous character of short-circuiting arcs emphasizes the need of the precautions which I shall mention in this paper; having in mind the avoidance, as far as possible, of such accidental short-circuits.

The expulsion tube air switch operated up to 25,000 volts, but failed at 40,000.

The "K" oil switch operated satisfactorily on 1,200 to 1,300 K. V. A. up to 25,000 volts, but at 40,000 volts it spat fire and

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occasionally emitted black smoke, thus seeming to be working at the limit of its capacity. No attempt was made to open short-circuits with the "K" switch.

The "H" oil switch never failed to open 1,200 to 1,300 K. V. A. at any voltage up to the maximum employed, 40,000; the circuit opening noiselessly and without the appearance of fire or emission of smoke at the switch. It was used as an emergency switch in all the tests to open *short-circuits* on 25,000 to 40,000 volts. The results of these and other tests, and the continued effective operation of the type "H" switch in the Metropolitan station indicate that this type of oil switch will safely control circuits of practically unlimited power at potentials considerably above 40,000 volts, probably as high as 100,000 volts.

The character of the break when operating properly was the same in all the switches except the open air type. In opening, the arc held for a number of half-waves from 6 to 18 and then broke at zero value without disturbance of the system. With the oil switches no traces of oscillation were noticed before the break, and no traces of rise of voltage. With the expulsion air switch, traces of oscillation were seen for a number of half-waves before the final break, and in consequence a slight voltage rise occurred.

I will not attempt to describe the numerous observations made at the Kalamazoo tests, as these will undoubtedly be given to you by our President, who supervised these tests and to whom I am indebted for the information which I have given regarding them.

In addition, however, to the production and use of a switch, which will be as safe and reliable as engineering skill can make it, there are certain other factors which should be considered in connection with the control of current for high-potential stations which should be taken into consideration by the electrical engineer. It should be constantly kept in mind that no apparatus can be absolutely free from accident, no matter how carefully designs are constructed. The engineer should, therefore, carefully consider the possible effect of any accident, with particular reference to the possibility of an accident to one element involving other apparatus. The layout should be such that an accident to one element could not of itself, or in consequence of a chain of accidents, result in a breakdown of the entire generating station, even for a short time.

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The mechanical engineer has considered this point and met it with a fair degree of success in the large modern central station with the fire-proof boiler house and the frequent subdivision of this boiler house into two or more portions by suitable fire walls, as in the case of those of more than one story.

The general employment of a duplicate system of steam piping, or its equivalent, also provides a reasonable safeguard against failure of supply from accidental disarrangement of a steam system. The steam engines in well arranged stations, being important units, are placed a sufficient distance apart, and so disposed, generally, that an accident to one will not easily involve other units. This is also true of the dynamos which are directly coupled to the engines.

The switchboard with its switches for controlling and appliances for measuring the output of the generating station, the cables leading from the generator to the switchboard, the location of the bus-bars, and the disposition and arrangement of the feeder cables for distributing the current, have not as a rule been given that serious attention which their importance deserves. In fact, the consideration of the electrical controlling devices and the wiring of the station has been apparently left to the last, and it is frequently the case that a generating station containing apparatus of great value has been jeopardized by the lack of careful design of the switching appliances. Stations designed to deliver a normal output of from 5,000 to 10,000 kilowatts, at relatively high pressures, say 5,000 volts or upwards, frequently contain switches for controlling the generators and the feeders mounted upon the face of a long continuous panel, and so crowded together that in case of failure to open the circuits the resulting arc would be almost certain to involve adjacent switches and even possibly cripple the station for a time. The bus-bars are also often so disposed that an arc may easily start thereat or at least so that an arc, if started for any cause, would be liable to seriously damage the switchboard.

The same methods frequently obtain in regard to the manner of installing the conductors; high tension and low tension conductors being often mixed together and the conductors so arranged that in case of an injury to one, other of the conductors leading from the generators or from the switchboard out of the station are in danger of being involved.

These methods have probably arisen from the fact that up to

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a comparatively recent period the service of a city for lighting and for power has been separated among a number of different stations, each of a relatively limited amount of power. In case of the failure of any individual unit in such case, as of the generator, switchboard, or other apparatus, the damage was small, owing to the limited energy available. A shut-down, even of the whole station, was comparatively unimportant. However, the case is quite different with the large modern station with output of from 10,000 to 100,000 horse-power, which is designed to supply electrical energy for a large portion of a city's needs, combining frequently electric power for traction purposes, electricity, for lighting, etc. The economies expected of such stations —lower cost of operation, smaller investment, and greater economy in coal and in steam—due to the better load-curve obtained by the concentration of loads of large area and of various character in one station, as well as to the higher efficiency of the large units, are familiar to all electrical engineers. I am inclined to think, however, that the possible dangers of such a concentration of energy have not been fully realized. The failure of such a station, even for a brief period, would be a disaster which, with proper design, need not occur.

I will briefly outline the principles which I believe should govern in the layout of such a central station, the details of which may naturally be varied considerably to suit local conditions. It should be kept in mind that I am discussing stations of normally large output, say 5,000 kilowatts and over, although many of the principles mentioned could probably be applied with advantage to stations of smaller size. Broadly speaking, I would carry the principle of subdivision into units as far as practicable; the units to be chosen with respect to the size of the station, character of load-curve, etc. The boiler house, as already stated, should be subdivided into two or more distinct portions, so that injury to one will not involve the entire steam system. Fortunately, the foundations, masonry and mounting of boilers are so essential and of such a nature that damage to one unit is not liable to involve another. At the same time, it is important that the boiler house should be divided into two or three sections, separated from each other by brick partitions. The steam piping should be in duplicate or a substantial equivalent, and so arranged that the bursting of a steam main cannot flood all the boiler rooms with steam or stop the entire flow of steam to the engine room.

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The engines, with the dynamos coupled thereto, may be placed in one large room, provided this room is of sufficient size to enable the units to be placed at proper distances apart. The switchboard should preferably be placed in a separate room, so that any accident to the engine or to the steam piping will not injure the switchboard operator or the switchboard mechanism. The electrical conductors from each dynamo should be led to the switchboard as far apart as possible from those of other units. Each set of conductors should be led to its own switch. Each switch should be of ample capacity to interrupt the entire output of the generator at full voltage and even take care of the concentration of the entire load of the station, as in a short-circuit. This switch should be placed in a cell of fireproof material and preferably electrically controlled from a central point. If so disposed, these switches may be placed reasonably close together, but the partitions should be such that any one of the switches could arc to destruction without involving the switch of a neighboring generator. Switches should be in duplicate, so that in case of failure of one, another switch will be in readiness. Especial care should be taken, in leading the conductors from the switches to the bus-bar, to keep the conductors as far as possible from those of neighboring units.

The bus-bar or bars should preferably be in duplicate, or some equivalent arrangement such as sectional subdivision should be adopted. Bus-bars should be carefully protected in fireproof compartments so arranged that it would be impossible for any arc to short-circuit from one conductor to another or for it to be injured by an arc caused by the destruction of any of the generator or feeder switches. The same care should be taken to isolate the conductors leading from the bus-bars to the feeder switches. The feeder switches should also be in duplicate; that is, two separate sets of switches on each feeder in series with each other when feasible, or the conductors leading to a group of feeders may be joined together by a switch placed in series therewith controlling a group of feeders. Each group series and each of the feeder switches should be mounted in its own separate fireproof compartment and preferably controlled electromagnetically from a distance. The conductors leading from the feeders out of the station should not be massed together in one conducting trench or well, but should be subdivided into as many groups as circumstances will permit.

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The constant aim throughout the entire station should be to limit the normal flow of energy in a given space to a pre-determined amount, preferably for example, to that of the generator unit which has been selected, or in the case of the feeders leading outside the station the normal flow of a group may be limited to that delivered to any one sub station.

It is obvious that the arrangement of switchboard, as described, will occupy more space than the ordinary panel type. The total space occupied, however, is but a small portion of the total space required for the generating plant, and it is believed that the precautions recommended are essential to the continued success and reliability of large generating plants. Such separation of the switches, etc., makes some method of control from a distance very desirable. The motors used for operating the switches may be either pneumatic or electric. The control of these motors should preferably be electric in all cases. By adopting electric control from a distance, it is possible to combine all the switches required for the generator, feeders, etc., upon a small keyboard under the observation and control of a single operator. It is also possible to place this operator in such a position that he will have a comprehensive survey of all the measuring and controlling devices needed for the station, and at the same time be free from danger in case any of the apparatus should fail to perform its work. Under such circumstances the operator is much less liable to make a mistake, and it is believed that having taken such precautions accidents even of a trivial character will be more unlikely to occur. In laying out the electrical devices for such a station the utmost simplicity should be aimed at; not a single instrument, conductor or switch being placed in the station that has not been carefully considered and felt to be essential. It is better to err on the side of simplicity than of complexity.

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Discussion.

Papers by Wm. S. Aldrich, F. A. C. Perrine, Charles F. Scott, Charles P. Steinmetz and E. W. Rice, Jr., Buffalo, August 22d, 1901.

Vice-President Dunn [*Chairman*]:—As was our practice yesterday, all of the papers will be thrown open for discussion simultaneously. Mr. Steinmetz, on account of presenting a paper himself and having read Mr. Rice's paper, has asked me to remain in the chair during the discussion. The papers are now thrown open for discussion, which it is hoped will be full and profitable.

Prof. Geo. D. Shepherdson: The point brought out by Dr. Perrine, that the loss by the brush discharge depends upon the radius of the curve of the conductor, indicates two or three interesting conclusions. One is that a solid conductor is preferable to a stranded conductor; at least, after being once erected. Of course, it may involve difficulties in erection when we get into large sizes. Another conclusion is that after a certain point is reached aluminium will be much preferable to copper, on account of its larger size. That may be of importance in two ways; one is that higher voltages may be practicable with aluminium conductors than with copper; the other point is that it may be practicable to transmit small powers over a greater distance with aluminium than with copper. Of course, that is modified by the relative costs of copper and aluminium, but a case might very easily arise where aluminium would cost more, relatively to copper than it ordinarily does, and yet it might be preferable on account of the possibility of carrying power farther at a higher voltage, or of carrying a smaller power over a great distance.

Mr. Henry W. Fisher:—I have been very much interested in Dr. Perrine's paper, especially with reference to the flattening of the e. m. f. curve due to capacity, particularly so as I made some tests a number of years ago which seemed to show the other effect, and I thought it might be interesting to tell how these tests were made. A 2500 k. w. generator was used, operated by the Allegheny County Light Company of Pittsburg. From this generator a 2000-volt circuit led to an auto converter and was taken from the auto converter to a high-voltage converter, and from the secondary of said converter to some lead-covered cables, one side being connected to the conductors and the other to the lead sheath. The instruments used for getting a comparison between the average and maximum voltages were a Weston voltmeter and a spark-distance measuring apparatus. The spark-distance apparatus was placed across the high voltage end of the converter and the curve for spark distances found up to 10,000 or 12,000 volts. Having determined the above on the same evening, with the same generator, all the conditions being

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as nearly alike as possible, connection was made to about 3500 feet of cable having a capacity of, say, .2 or .3 microfarad, and it was then observed that the spark distances were greater for given voltages. In order to make sure that there was not some change in the outside circuit the cable was cut off and the same tests made without any capacity. The spark distances were the same as at first. This leads to a very important fact. If capacity on the line does flatten the e. m. f. curve, the spark distance must be affected by this capacity to the extent of increased spark length for decreased maximum voltage. Or else it may be that the sharpening or flattening of the e. m. f. curve varies with capacity, self-induction, etc., and with a small capacity it might have one effect, with a larger capacity the other.

The experiments were conducted so carefully that I am certain under the existing conditions the e. m. f. curve was made sharp. Experiments were then conducted with the same generator at different hours of the evening, and it was found that when the generator was heavily loaded in the early part of the evening the spark distances were smaller; and later in the evening, when the generator was not so heavily loaded, the spark distances were larger. With the capacity in multiple the spark distance was increased about 10 per cent. I wished to bring up these points because I thought some one might be able to explain this apparent difference between Prof. Perrine's results and those obtained as shown.

MR. W. L. R. EMMET:—There are two statements that have attracted my attention in these papers which seem to imply a certain limit of the usefulness of electrical apparatus through possibilities of trouble which may occur in its use. I call attention to them in the general interest of electrical engineering. One of them was in Mr. Scott's paper. He rather implied that it was necessary to design dynamos, motors and rotary converters to suit one another; that the synchronous motor must be adapted to the condition of its operation, and that if the voltage was not exactly adjusted it gave rise to troublesome, expensive or destructive fluctuations of current or voltage in the system. I do not think that in practice those troubles have ever existed. Neither does it appear necessary for any skilled manufacturer of such apparatus to say to a producer, "This is only adapted to use with motors of a particular design, and with certain kinds of rotary converters, and if your conditions are altered and you have to put something else on your system, troubles will arise." Take, for example, the action of the synchronous motor with variations of the e. m. f. wave in a generating plant, or variations of speed in a system, or variations of voltage in a system. In the case of variation of the e. m. f. wave the differences between the inherent wave of the synchronous motor and of the generator, are ordinarily differences of considerably higher frequency than the main wave of the system. They are simply overtones which are

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largely obliterated by the effects of self-induction, and the worst that can result are certain cross currents in the period of those overtones. These are so small relatively to the main oscillations of the system, that they are inappreciable; and in practice rotary converters and synchronous motors operate all over the world, on all sorts of e. m. f. waves, and under all sorts of variations and conditions, and the troubles are apparently as infrequent where there is no conformity of wave as where there is perfect conformity. Practical experience teaches us that synchronous apparatus, operating in parallel is, in spite of these theoretical difficulties, quite rugged and serviceable where the conditions of design are proper. Another matter which has been unduly dwelt upon by Mr. Scott is the importance of adjusting synchronous motor fields to conform to change of voltage on the line. The synchronous motor with fixed excitation tends to act as a steadier of the system, its variation of power factor with change of load being very small when the motor is ordinarily proportioned. While everything that Mr. Scott says about the usefulness of the induction motor is true, there are, as he also admits, wide fields for the use of the synchronous motor. In practical service the troubles which he has mentioned are not often sources of interruption.

The other point referred to was in Mr. Steinmetz's paper, where he mentions as incident to the use of certain circuit opening devices variations of voltage which are prohibitive and which cannot be provided for by insulation. There is a fact in connection with this matter that is of great practical importance; this is, the power of resisting such excessive strains which is possessed by certain types of insulation. Air in one sense, the simplest sense, may be considered the most perfect insulator. Dry air is a very perfect insulator. It requires very high voltage to be punctured. The puncture of air, however, is something which involves no expenditure of energy. It is instantaneous and can occur simultaneously with the existence of the voltage capable of jumping that distance; whereas solid insulators, which are continuous and free from porosity and from openings, or from air passages, require considerable expenditure of energy to puncture. The excessive voltage impulses to which Mr. Steinmetz alludes are of very high frequency and do not continue long enough to effect the disintegration of the insulation, and as a consequence we see transformers short circuited through air across their terminals several feet apart, where the insulation is entirely unaffected. In point of fact, in some of the systems where the most trouble has occurred with rupturing of air insulation, arcing across the backs of switchboards and to adjoining pipes and structural work, there has been no trouble whatever with the insulation of the system. On this Niagara Falls system, there have been at times tremendous manifestations of e. m. f. about the connections at the terminal houses, indicated by the

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jumping of wide air-gaps, yet there has never been at such times any case of trouble with the insulation of the transformers, of any make. Furthermore, we see in lightning storms tremendous potentials applied to the lines, and yet no trouble with the insulation if it be of a certain character. If the insulation is such that air is depended upon, no matter how great the distance over the terminals, trouble is liable to occur under certain circuit conditions, for example, where a transformer has two exposed terminals three or four feet apart, it will short-circuit across those terminals through the air, but if it is properly constructed and suitable methods of insulation used, it will not be injured. A great deal can be accomplished in a practical way by observing those conditions and building apparatus to meet them.

DR. A. E. KENNELLY:—With regard to Mr. Scott's paper, which gives a distinct and useful differentiation between synchronous motors and induction motors, I think the comparison is somewhat severe to the synchronous motor. Only a few years ago we were very glad to have the synchronous motor, before the induction motor made its appearance, and now that the synchronous motor has its duties largely replaced by the induction motor, I think it is a little unfair to an old friend to underrate it. Moreover, in the mixed systems of long distance distribution I think it is desirable to employ both synchronous and induction motors, each in their proper spheres of action. Without synchronous motors the power-factor of a system may be unduly low.

I would also like to put in a plea for dropping that unfortunate word "rotary," in connection with converters. It seems to have become fixed in our minds that a converter must be a rotary converter. Of course, a converter, as we understand it, must go round; but would it not be possible on an occasion like this to take some steps for dropping an unnecessary word which plays no useful part?

As regards Mr. Steinmetz's very interesting paper, I think that it shows, from a theoretical standpoint, the importance which may attach to an evanescent constant in an algebraic equation. The evanescent constant which occurs in every alternating circuit equation, which we usually ignore and regard as vanishing after a few cycles, may, as he points out, rise to a prominence 100 times greater than the fundamental, and in such a case one cannot afford to ignore the evanescent constant. Its practical importance, of course, attaches to the great danger which may result from the short circuit of alternating-current mains under particular conditions. We believed that we had enough trouble with short circuits on direct-current generators, and when we had alternators which would refuse to give excessive currents on short circuit, we felt that we were comparatively free from dangers from short circuits on alternating-current systems, but owing to the surges which may occur in such

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systems we have a new danger, very formidable, under particular conditions. The difference between the surges which occur in the case of such a short circuit and the resonance which ordinarily may occur in the normal operation of a line is very interesting. In the one case the resonance in the normal operation of a line is dependent upon the harmonics in the e. m. f. wave, and if all harmonics were removed from the e. m. f. there would be no resonance. The case is one of forced oscillations. Certain harmonics are present in the applied e. m. f. which will force certain effects upon the transmission system under particular conditions. In the other case, of which Mr. Steinmetz has now made an analysis, and which he brings to our attention so lucidly, it is not a question of harmonics, but simply a question of the oscillations of a large system of conductors containing inductance and capacity; and no matter how these conductors may be charged, or the kind of wave employed, or the source of e. m. f., these dangerous oscillations may be developed under certain conditions attending sudden changes of current or pressure. A very curious instance is brought to our attention by Mr. Steinmetz himself in pointing out that the Wehnelt interruptions offer an analogy to these oscillations.

PRESIDENT STEINMETZ:—Mr. Chairman, Members of the Institute and Guests—I desire to say a few words regarding Mr. Scott's paper. While I can fairly agree with the second part of it I am sorry to be obliged to disagree from a considerable part of the first portion, giving a comparison between synchronous and induction motors. Whatever I shall say, and with all deference to Mr. Scott, refers to motors of larger sizes, since we all agree that in small, and very small sizes, the induction motor is preferable by reason of its simplicity, due to the absence of the exciter, and since in small motors the objectionable features of the induction type are not so serious and can be eliminated to a large extent by the judicious use of some large synchronous motors in the same system. I have controlled the design of some hundred thousand k. w. of induction motors and some hundred thousand k. w. of synchronous motors. I believe I have been fairly successful with either type, and so have no preference for one or the other design; but some years ago, when a discussion came up on this topic before the INSTITUTE, I made the statement that "I see no excuse ever to use an induction motor where a synchronous motor can be used," and my experience has not yet shown me any reason to change that opinion.

Coming now to the parallel columns, I must not only take exception to some things stated, but also add that a number of points have been omitted which appear to me essential for a fair comparison, as for instance, that there are two essentially different forms of induction motors, the "squirrel cage" motor which is ideal in its simplicity, but requires the same excessive starting current as the synchronous motor, and the rheostatic motor which

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consumes in starting the same current as when running with the same load, but requires rheostat and collector rings and brushes or switches. Obviously only a few of the statements can be discussed.

Regarding auxiliary apparatus, the "squirrel cage" induction motor, if required to start at moderate current, needs a starting motor just as well as the synchronous motor. The difference between the "some form of transformer for reducing the voltage" in the synchronous motor, and the "auto-transformer for reducing the e. m. f. for starting" in the induction motor, I fail to see.

Exciter and field rheostat are indeed not required for the induction motor, but armature rheostats with switches or collector rings are required if the induction motor shall give a good starting torque with moderate starting current.

All the statements regarding adjusting the field currents, which are repeated several times, are greatly exaggerated. With any reasonably fair synchronous motor, without adjustment of the field excitation but at constant excitation at all loads, the power factor will never fall as low as it is with the induction motor at the same load.

No "squirrel cage" induction motor with reasonable efficiency starts at full load excepting with currents many times larger than full load current, so that the "squirrel cage" induction motor should be started light, the same as the synchronous motor.

In the construction, the "field winding of many turns liable to accident" is in the synchronous motor not different from the field winding of a low voltage, continuous current machine, and the latter is considered nearly as safe as any piece of electrical machinery.

Collector rings and brushes or switches, and in addition a rheostat, are required in the induction motor if starting torque with moderate starting current is desired.

Here it should be added that the synchronous motor has the advantage of a good mechanical construction with a generous air-gap between stationary and revolving parts, while the induction motor to have a reasonable power factor must run with microscopic clearance between stator and rotor.

The synchronous motor is started by throwing a switch in starting, and then in running position, like the induction motor, and then gives the same small torque with large current. The only additional feature is that after the start the field switch of the synchronous motor is closed. The synchronous motor can, however, also be started with small current by the use of a starting motor which brings it to synchronism.

Neither the induction motor nor the synchronous motor when thrown out of step by overload will recover, excepting when the load is thrown off.

The starting of the synchronous motor is no more inefficient than that of the "squirrel cage" induction motor, and the maxi-

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mum torque of the synchronous motor is frequently greater than that of the induction motor.

No alternating current motor can operate efficiently at fractional speeds except by changing the frequency or the number of poles, etc., and the synchronous motor, as well as the induction motor, is essentially synchronous regarding speed.

Regarding current consumed in starting, I have never seen or heard of a large and efficient "squirrel cage" induction motor giving full load starting torque with 1½ to 2½ times full load current. Four to six times is as a rule nearer the facts.

The wave-form as a factor in explaining misbehavior of alternating current apparatus is rather discredited nowadays. While the influence of the wave-forms on the current can be observed in the induction motor, even more than in the synchronous motor, especially when running light, this feature becomes negligible at load.

The next paragraph of Mr. Scott's paper is the only consideration regarding the decision between synchronous and induction motor which I consider justified. It means that the use of the synchronous motor is restricted by certain limitations regarding steadiness of frequency, resistance of supply lines, etc. Where these limiting conditions are fulfilled, the synchronous motor does not hunt and is preferable to the "squirrel cage" induction motor. Outside of the limits of operativeness of the synchronous motor the induction motor must be used. Obviously where excessive starting torque and small starting current is needed the induction motor with variable armature resistance is appropriate.

As stated before, without adjustment of the field current, synchronous motors give power factors higher than induction motors, but by varying the field current the synchronous motor can be made to compensate for objectionable lagging currents produced by other parts of the system, as by induction motors. It is true indeed that the synchronous motor represents an active or live e. m. f. This frequently is one of its most valuable features, that, with the supply of electric power failing, the synchronous motor, and also to a lesser extent the converter, driven by engine power, is ready to turn generator, and so becomes the generator reserve of the sub station, supplying power to lights, induction motors and other dead loads on the system. This feature is utilized sometimes to such an extent that during the daily changes of load the synchronous motor regularly changes from motor during daytime to generator during the peak of the lighting load.

Regarding the summary, most of the statements have already been discussed. It should be, however, added here that the synchronous motor is smaller than the induction motor, more reliable in its operation, and is of a higher efficiency. It can be wound directly for voltages of 10,000 and more, which the

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induction motor cannot, and step-down transformers and the complication and loss of power inherent thereto can be saved. so that considering that the synchronous motor alone already exceeds in efficiency the induction motor, when compared with induction motor and transformer, the high voltage synchronous motor is vastly superior in efficiency. In operation and adjustment it requires no more but rather less skill than the rotary converter recommended in the last part of the paper under discussion. It appears, therefore, that the synchronous motor and not the induction motor is the type especially suited for transmission and distribution of power in large units, and the induction motor finds its proper field in power distribution in small and moderate sizes and for special applications, such as frequent starting under heavy torque, and then as a special motor.

Now, from all this, the conclusion I derive is that the synchronous motor is by no means the decadent apparatus, that Mr. Scott apparently states, but is not only alive, but is preferable as a type of machine; that it is the machine which should be used wherever possible; but that there are certain limitations outside of which the induction motor must be used because there is nothing better.

As to this very high power factor of the induction motor, we must consider that even if the power factor in special cases, with a special low frequency motor, exceeds 95 per cent., the average running power factor probably does not exceed 90 per cent., but if anything is lower. A 90 per cent. factor means 44 per cent. inductance factor or 44 per cent. of lagging alternating current and a corresponding reaction on the system and on the regulation of the generator.

Dr. F. A. C. Perrine:—I wish to add something to President Steinmetz's remarks, from my own experience as an operator of induction motors. From that experience I would say that the advantages set forth in the paper are largely possible advantages, and while any one of them may be found in a particular case, the conclusions drawn do not generally apply together. As regards the point made by the President concerning starting torque with 1½ times full load current, I know of one case where a 400-h. p. induction motor was built and guaranteed to start with 1½ times full load current, the contract between the user of the current and the transmission company having been made to require it. In that case it was necessary to insert four friction clutches between the motor and the flour mill operated by it. The first friction clutch was between the line shafting and the rolls, and so on; all of which was necessary in order to start up that induction motor and keep the starting current down to 1½ times full load current. In another case, also in a flour mill, where a high efficiency induction motor was demanded, the starting current was so great that a 450 k w. generator would not start a 300 h. p. induction motor. The water-wheel attached to the 450

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k. w. generator was slowed down by the power demanded to start up the motor, and in addition it was found necessary to use a number of men pulling on the belt. At first the superintendent said it was a good thing, because he never had had his men on time before. With the motor in service they had to come early in order to pull on the belt and start up the mill. This was finally found to be a burden, and the owner demanded that the induction motor be re-designed so that it could start up alone. The manufacturer changed the end rings on the "squirrel-cage" armature, and the motor would then start the mill without any difficulty. But the mill was paying for its power by wattmeter, and the cost of the power was increased by one-half cent a barrel of flour on account of the decreased efficiency of the motor.

And now, as regards the impossibility of running transmission plants with synchronous motors, while I in general agree with Mr. Scott that it is not advisable to put synchronous motors into all hands; at the same time, as Dr. Kennelly has said, the synchronous motor is an old friend, and in California one of the earliest transmission plants is using almost entirely synchronous motors, and its load is almost entirely mining plants. Now, there is not a plant in California which is giving better service to its customers, or a more constant voltage regulation, than that particular plant. Again, I would remark that a paper very much similar to this was discussed before the Pacific Coast Transmission Association, and the concensus of opinion amongst the operators of the transmission plants there seemed to be that for large powers it was, as a general rule, inadvisable to use induction motors, but even at the expense of sometimes putting synchronous motors in the hands of operators who did not understand their effect on the power factor of the circuit, it was as a rule a preferable thing to use a very considerable number of synchronous motors on a line, and as a general rule a good plan to use synchronous motors where large motors were supplied. Again, experience in California has proved very conclusively the point Mr. Steinmetz made of the advisability of having the synchronous motor as a portion of the steam reserve. A serious drouth occurred in California about four years ago and continued for two years. During that time a statement was made which was nearly, although not quite true, that every synchronous motor in California was running as a generator supplying current which would have required duplicate machinery had those plants been operated with induction motors.

Another point I wish to call attention to in Mr. Scott's paper, is the observation that for transmission work in general, as I understood him to say, for the operation of rotary converters as well as induction motors, it is necessary to design the generators far below the point of saturation in the field. I think that designers and operators will agree that, though it may be that 60-

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cycle rotaries are successful in some cases, nevertheless, the 25-cycle rotary is a more successful machine; and so far as I am aware, all designers of 25-cycle generators are running their induction up in the fields about as high as the iron will allow; and in spite of that fact the 25-cycle induction motor and the 25-cycle rotary work as well, if not better, than at 60-cycles, where the induction in generator fields is kept down, necessarily, lower on account of the closeness of the field magnets.

MR. L. B. STILLWELL:—I confess, Mr. President, that from my experience I am a friend of the induction motor wherever it can be used. I think we are indebted to Mr. Scott for his very compact comparison of the advantages and disadvantages of the two classes of motors. I do not think it is an answer to that comparison to allege that the differences shown are theoretical. I believe Mr. Scott is fully competent to discuss it from that standpoint, and I wish simply to mention one or two points which I have met in experience in operation, which have led me to prefer the induction motor in practically all cases in which it can be used. The rotary converter is necessarily synchronous with the generator. That is a fact which I have sometimes regarded as unfortunate, but at any rate we cannot get around it unless we are willing to go to the expense of buying a motor to drive a direct current generator for railway work. But the practical advantages that have been claimed for the synchronous motor, I think, reduce themselves to this one claim, that the power factor of your system as a whole is improved by its use. As to relative efficiencies there is some advantage in the synchronous motor possibly, but nothing very material. As regards the power-factor advantage it is apparent rather than real in operation. In a large system, such as exists in Buffalo to-day, we cannot have thoroughly skilled men in control of the stations adjusting the fields of the rotary converters and the synchronous motors with a view to affecting properly the power factor of the system. If we could put a synchronous motor in a terminal house, to which all of the overhead lines were connected, and there provide skilled attendants, it might have some value; but where you have a dozen substations, as is the case in the Niagara plant, you must put these synchronous motors and converters in the hands of not less than 24 operatives, since you must have at least two shifts for each sub-station. Now, the Buffalo companies pay men of that class about $50 a month, and it is not an easy matter, as I know by experience, to find men who will work for that wage and who are to be trusted with the manipulation of machinery requiring synchronism. Mr. Scott has pointed out the fact that there are a great many mistakes made in synchronizing the motor with the system, and it ought to be remembered that those mistakes are made, not by members of this Institute, but by $50-a-month men.

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As to the starting current of these motors, I am sorry that I cannot find myself in agreement, from experience, with our President in his discussion of Mr. Scott's paper. I recall one instance in which a rotary converter rated at 375 k. w. connected with a large system required so much current in starting that the men thought that the pointers at the ammeters were going to move clear off the instrument and never come back. It took apparently five times the kilo volt-amperes that it should have taken, and to-day the most satisfactory rotary converters, to my mind, that are operated from these large power plants are those which use induction motors to start with. I cannot say how it is to-day, but when I saw it not very long ago one of the stations at which the rotary converters had been made self-starting had been forced to abandon that method of operating and to start from the direct current side, by direct current obtained from another rotary converter, which was started by an induction motor.

There is one other point that I would emphasize as objectionable in the synchronous machinery, and that is this: in an independent system it is inevitable that there will be short-circuits. The cables in some parts will break down at times. If the circuit breakers in the sub-stations and in the power house can be suitably arranged it is possible, at least theoretically, to localize that trouble if the motors used are such that they will not instantly fall out of step when the momentary drop of potential occurs. Now, it is true that these synchronous motors and rotary converters are supposed to drop out of step only when the potential drops to about 50 per cent. of the normal value. That may or may not be so, but there are occasions when the potential does drop to 50 per cent. of the normal value and these machines let go and stop when I am satisfied that an induction motor would not let go. The lighting system of the city of Buffalo to-day is operated by synchronous motors. To my mind it would be better to operate it by induction motors, for the reason that at times, not so infrequent as we might wish, there will be momentary drops of potential, caused by short-circuits. These may last only half a second, but half a second is a long time when measured by alternations of current, and it is long enough to make these machines let go, and then the service is interrupted. This may be answered by saying that the regulation of the machines at Niagara Falls is not first-class as judged by modern standards, and that is true; but the improvement that can be effected by bringing up the regulation of the generators is a quantitative one and I am not at all sure that with the best that can be done in improving the regulation of the alternators we shall escape the difficulty that now exists, in view of the fact that we have line drop and drop in the transformers, as well as drop in the alternators themselves.

As to wave shapes, it is true that the power company has not had any trouble very recently with the operation of synchronous

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motors or rotary converters from that cause; nevertheless, it seems to me that it is wise in designing machinery to attain as nearly as possible a perfect sine curve. I regard it as a misfortune that the potential curve of the Niagara Falls alternators is flattened, and we have sometimes suspected that a third harmonic was responsible for some of our cable troubles.

It seems to me that the argument that you need pay no attention to wave-shapes because inductance tends to reduce them to a sine form, is on a par with the argument of a man who should say, "It is no use to cut gears with great care, because they will wear themselves all right if you give them time."

As to the clearance of the induction motor, it is true that it is necessarily less than the clearance of a synchronous motor of corresponding output, and for this reason, mechanically, the motor is not quite on a par with the synchronous motor but I have never known a case where in America the small clearance has led to trouble. If $\frac{1}{32}$th of an inch has been used abroad in some of these transmission systems, I can well imagine it would be very difficult to keep the machines lined up; but with ordinary care I believe a good clearance in the induction motor will admit of a power factor at full load of 90 per cent. and upward, which is sufficient.

Mr. Oberlin Smith.—Mr. Scott's paper interested me very much in its presentation of the deadly parallel columns. The left hand one seemed to involve almost as much as the rules of golf, and to involve also the consulting engineer, which in that game we call the caddie. This may probably be one of the objections to the synchronous motor, where it is used in numbers about an establishment, rather than its small size. I am not competent to judge of it in station work, not being experienced in that line. Very likely these motors have much value where conditions are uniform and the plants are large. I speak, however, rather from the standpoint of the user and adapter of motors, than from that of the maker and designer,—from the standpoint of the mechanical engineer. Now, there is one very important field that small motors can occupy; that is, running individual machine tools, including presses, for punching, shearing, drawing and such work. I believe the time is coming when all our new machine shops, where it is not an object to save an old plant, will do away entirely with shafting and belting and use individual motors. We have not quite got to this ideal condition yet. We have in some shops, to a great extent, carried out the principle, but there is much more missionary work to do. An important question that is to be solved in the immediate future, is whether these motors will be continuous current machines, such as are now mostly used, or whether alternating current can enter the field. Very probably it can, but in such cases it seems to me that the induction motor must be more suitable than the synchronous, because of its simplicity. As a

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mechanical engineer, I think the induction motor will appeal to all of us of that profession as much the simpler machine, where you simply have a rotary shaft running through bearings, and where it will run of itself, as has been expressed by Mr. Scott—go on of its own account and be happy. Whether synchronous motors always will thus remain joyful may be open to doubt. What we want of you electrical engineers and designers are motors and dynamos which we can take into this large growing field, the running of individual machines, of ordinary machine tools. As we all know, with most of them, such as lathes and drilling machines especially, the load varies enormously, as well as the speed. We want a motor that will give us as much change of speed as possible; but as we can not expect all that is necessary we must get the rest of it by change-gearing, etc. In running presses and punching machines we don't want much, if any, change of speed, but we do want very great variation of load; and I think the special attention of designers of small motors of this kind, in the coming years, should be directed not only toward improving them but toward getting them in shape to be made on the "duplicate plan," so that we can put them in without their costing a great deal. Moreover, we must have the simplest possible motor in its mechanical construction, in its operation, and in its necessity for attention. If we can use the alternating current, with induction motors, so much the better. In many cases we want an individual plant for a machine shop, with the generator on the premises, not depending on outside current, and which shall run the machines individually or run them in small groups with short lines of shafting. For this service we obviously must have as simple as possible a machine, and something that can be purchased very cheaply.

MR. MERSHON:—I am very much interested in the paper by Dr. Perrine, as it bears on a subject to which I have given a great deal of attention. The results of the Telluride work to which Dr. Perrine refers, on the losses occurring through the air between wires at high voltages, form a considerable portion of a paper* read before this INSTITUTE at Omaha in 1898 by Mr. C. F. Scott. This work was done by me and my assistants, and under my sole direction, and the results of it represent much time and patience and were obtained under very difficult conditions. The question of the variation of loss as the size of the conductors is varied was not treated in Mr. Scott's paper, neither was it taken up in the report of mine from which Mr. Scott obtained the results of my work, for the reason that there were no facilities at Telluride for taking measurements on the high voltage losses between wires of different sizes, there being available only one size of wire.

But it has been known, I think, for some time that the loss between wires depends on the radii of curvature of the wires

*TRANSACTIONS, vol. xv., p. 531.

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themselves. I think it is pretty well recognized that the loss is a function of the rate of fall of potential at the surface of the wire, which rate of fall of potential is a function of the radius of curvature of the wire and of the distance between wires. When the distance between wires is large relative to their diameter the variation in the rate of fall of potential at the surface of the wire is comparatively small as the distance changes and, consequently, changes in distance do not make much difference in loss, whereas changes in the sizes of wire may make a very considerable difference. I think the remark which was made afterwards, that the loss with stranded conductors will probably be larger than with solid wires, is a point well taken, although the difference will be less after the conductors have been exposed to the weather, because the solid conductors themselves will become more or less roughened, and this in itself determines to a great extent the losses that occur. It is very difficult on that account to determine experimentally the law of variation of loss with different sized conductors, because it is almost impossible to get wires which are uniformly smooth, or uniformly rough, whichever way you may put it. I have been endeavoring lately to get a few measurements in an entirely different way from that which was adopted at Telluride, but so far the results have not been very consistent. A knowledge of this law is essential to the general solution of the problem Dr. Perrine mentions, namely, what is the best voltage, from the standpoint of line losses, to use in the case of any given transmission. There is a point which Dr. Perrine has not mentioned, which is of importance in connection with that portion of the line loss which occurs between conductors, and that is, that in cases where high voltages are used, the drop in voltage over the line will be considerable, so that the loss per unit of length of line will be less as we go along the line from the generating to the receiving station. As a result, while we may start out with a very formidable loss between unit lengths of the line conductors, the total loss between conductors over the whole line may be comparatively small, because the loss per unit of length has fallen to a small value or even to zero by the time we have reached the receiving end of the line, or it may have fallen to zero before we have reached the end of the line. The loss between wires is largely dependent on the wave form existing on the circuit. A peaked wave form runs the loss up very greatly and a flat wave form does the reverse. As regards the effect on wave form, I noticed that Dr. Perrine spoke always of the "flattening" of the wave form. I do not think it is necessarily a flattening. It may be either a flattening or a sharpening, depending upon the relations between reactance and capacity in the circuit and the original form of the wave. I have obtained both effects, and very markedly, and in addition to that I have obtained the jagged waves.

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As regards the question of the power factor of motors, I do not want to go into a discussion on the relative merits of synchronous and induction motors as I was in a similar discussion yesterday but I will say this, that I lean toward the induction motor when it comes into competition with the synchronous. However, I think that, as I said yesterday, each motor has its own place and its particular sphere, and it is a question of judgment as to where one sphere begins and the other ends. But there were one or two points made with which I cannot quite agree. One of them is as to the power factor which can be maintained under working conditions with the synchronous motor. I do not think it can be maintained at anything like the figure that is ordinarily given. As to the synchronous motor, connected, as Mr. Steinmetz suggested, without any field rheostats, I do not think there is any circuit operating in this country, unless with phenomenally good attendance, where a power factor of 95 would be maintained. I think the change in voltage on the circuit, the change in resistance in the motor field and all the other changes that would occur, would cause the power factor to vary a considerable amount from this value.

As regards the relative efficiency of the two machines, I am not going to speak from the standpoint of design, but I would like to speak from the standpoint of the men who are receiving competitive bids. Some time ago I had occasion to prepare specifications for motors, motor generator sets of considerable size, and I asked for bids on both synchronous and induction motors. The machines were in the neighborhood of 500 k. w. capacity. The efficiencies guaranteed by the different competitors were almost exactly the same. They were practically the same on induction and synchronous motors from the same makers. I may say also that on those sets the power factors guaranteed for the induction motors at full load were in one case 92, and in the other 92½ per cent. which I thought was pretty good.

VICE-PRESIDENT DUNN:—Gentlemen, one of the greatest pleasures of our present Convention is the presence of our foreign visitors. We have enjoyed hearing from them in the previous discussions, and I should now like to extend the floor to our distinguished guest Mons. Paul Janet of Paris, delegate from the International Society of Electrical Engineers.

PROF. PAUL JANET [*Translation*]:—I regret that I have not had sufficient time to study, as it deserves, the important paper of Mr. Steinmetz on accidental rises of potential in alternating current conductors; however, I desire to bring to your attention, as a case which is probably closely related to this line of thought, a certain interesting accident which occurred on a high-potential, three-phase, underground line during the Paris Exposition, in 1900. A feeder of this net-work was run along one of the temporary passage-ways built over the Seine for use during the Exposition. A workman, through carelessness, hammered a nail

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into this cable, and thus caused a direct short-circuit, and probably also a strong arc; now, there were noticed under those circumstances, two ruptures of the cable insulation at points distant two or three kilometres from the point where the accident occurred. This fact seems to me to be closely connected with, and to come under, the theories of Mr. Steinmetz.

With reference to the interesting parallel between synchronous and induction motors presented by Mr. Scott, I am reminded of still another accident which I would like to relate to you, for, in truth, the study of accidents will ever be more instructive than the study of normal working. In this case, there was a long distance transmission (40 kilometres, or about 24 miles) with high-tension tri-phase currents (12,000 volts). Some repairs being necessary in the overhead line, word was sent by telephone to the generating station to stop the generators. This order having been executed, the workman in charge of the work touched the wires, and received a shock, the line having retained its potential in spite of the stoppage of the generators. Here is what had happened: in one of the receiving stations, a synchronous motor was working in parallel, driven by a turbine; the current having been cut off, the turbine had continued to turn, and had driven the synchronous motor, which thus became transformed into a generator, and, by means of its transformers, had kept up the potential on the line. Such an accident could evidently have been avoided by the use of an induction motor, and from this standpoint, the latter seems to insure much greater safety; but we should not, nevertheless, attach too much importance to this kind of consideration, for it is not difficult to introduce automatic appliances which might cut off the current in such a way as to isolate the line in a case of this kind.

PRESIDENT STEINMETZ:—I desire to say in answer to our distinguished foreign visitor, that such apparatus as he has mentioned as being designed, is in actual operation here. Such reverse-current circuit breakers which cut off the current in case of a reversal are, I believe, in operation here at Buffalo on the Niagara system.

There are several other points which I should like to discuss. One is the question as to loss of energy in stranded conductors. I have not investigated this particular feature, but some investigations of the disruptive effects and luminous discharges at very high voltages, lead me to believe that the loss with stranded conductors will not depend so much on the radius of curvature of each individual strand, but on the radius of curvature of the total cable, for the following reasons: At very low and relatively low voltages, the surface condition of the conductor, or terminal, is of very great importance. The higher you go in voltage the less important this becomes, until ultimately, at very high voltages, the surface condition is entirely immaterial, and even spheres and needle points are practically alike, which means, in other words,

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that very high voltages at terminal operate not on the actual surface of the solid substance, but a space, of practically uniform curvature, surrounding the surface, that is, the space covered by the luminous or brush discharge, and thereby brought in electrical communication with the terminal, and, therefore, I should believe that a stranded cable would act like a solid conductor of the same external diameter.

Now, regarding one more point, that of the synchronous and the induction motors at low voltage. Obviously, the advantage of one or the other motor depends on the shape of the torque curve, and no one has ever mentioned, and I know of no publication on, the shape of the synchronous motor torque curve, as a function of the impressed voltage. Some years ago I had, however, some careful investigations made which led me to the conclusion that the maximum torque of a synchronous motor, within a certain range, varies in direct proportion to the terminal voltage, so that a drop of voltage of 10 per cent. will lower the maximum torque of the synchronous motor only 10 per cent., while we know that in the induction motor the maximum torque varies with the square of the impressed voltage. Thus, other things being equal, the synchronous motor with low voltage will maintain its torque longer than the induction motor. The reason probably is, that with the induction motor the two factors of torque, the magnetic field intensity and the induced armature currents, both decrease with the impressed voltage, while with the synchronous motor, the one factor, the field intensity, is at constant field excitation, more nearly independent of the impressed voltage. The synchronous motor is sensitive, however, to rapid changes of frequency.

PROF. ALDRICH :—In regard to the paper by Mr. Scott, we have had some experience in throwing in induction motors on synchronous motor circuits, and found as mentioned, very pronounced disturbances, especially when the synchronous motor is operated on a circuit with marked phase displacement. An induction motor may be thrown in on a synchronous motor circuit practically without any regard to the load on the induction motor, when the synchronous motor is operated at or near its normal excitation; that is, essentially at unity power factor. The synchronous motor would repeatedly break down when the induction motor was thrown upon its circuit if the synchronous motor were over-excited, so producing heavy leading currents equivalent to a large capacity effect on the line. The object in view was to neutralize the capacity of the over-excited synchronous motor with the inductance of the induction motor. It was found impossible at times to effect complete neutralization. In practical operation it is usually necessary to bring the synchronous motor to normal excitation or unity power factor. The induction motor may then be thrown in, and the excitation of the syn-

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chronous motor increased above the normal with its corresponding condenser effect to offset the inductance. The machines cannot be instantly or suddenly thrown in under any load or with any excitation. That is pointed out in Mr. Scott's paper. Your attention is merely invited to this as an experimental demonstration. We have repeatedly tried to corroborate these principles in the laboratory. Perhaps there are others who have similarly used much larger commercial units.

Another point is brought to our attention in this relation; namely, the large current carrying capacity of the synchronous motor required. We used two, four and seven k. w. induction motors on a 7½ k. w. synchronous motor circuit. With such varied induction motor reactances it was practically possible to effect neutralization, bringing the circuit to unity power factor. Conditions arose, however, in the synchronous motor where with practically no load upon it, a 100-ampere fuse would be blown, which was much over the normal rated capacity of the machine. Unless precautions are taken under these and similar conditions of extreme phase displacement fuses will be blown under no load.

DR. PERRINE:—As regards the influence of stranding conductors, I think Mr. Mershon and Mr. Steinmetz between them have answered the objection. The influence is dependent upon the distance between surfaces, and where you have the separation that is given in an ordinary transmission line, the stranded conductor acts practically as a solid. This makes possible the use of aluminum for such lines, and bears out the observation that with aluminum we can transmit less power than we could otherwise, where very high potentials have to be used. Aluminum is a very difficult material to use as a solid conductor and is practically limited in its use to strands, owing to the qualifications of the wire as regards splicing and many other practical details that it is not necessary to go into. Regarding the point raised by Mr. Fisher and also by Mr. Mershon that under certain circumstances the capacity will actually produce a hump in the e. m. f. curve, rather than a depression—that is true. It is generally the case with ordinary circuits and ordinary wave-forms, that out along the line—not at the generator—the e. m. f. wave will be found depressed. As I attempted to show, in calling attention to the fact that the paper as originally printed was not entirely correct —the effect in itself is very complicated. In determining the wave-form at any point we have to take into account the resistance, self-induction and capacity together, as well as the initial harmonics of the wave-form, and the fact that under certain circumstances a peaked wave is made, essentially, is shown very clearly in Fig. 1, page 365 where the harmonics of the e. m. f. wave, which are almost imperceptible in that wave, become decidedly peaked harmonics in the current wave; and the statement should be simply, that the effect of capacity generally is to

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depress the peak of the wave, although that is not altogether true. In some cases, under very many conditions, the effect of capacity is to give peaks which coincide with the harmonics that are in the fundamental.

VICE-PRESIDENT DUNN:—The floor is now extended to Mr. Scott for the closure of discussion on his paper.

MR. SCOTT:—I will limit myself to a few general statements which will cover quite a number of specific points which were brought up in the discussion upon my paper. Both President Steinmetz and Mr. Emmet pointed out quite truly that the various so-called theoretical difficulties in the adaptation of synchronous motors to the circuit, were fortunately those which were seldom of actual occurrence, but both of the gentlemen used substantially similar expressions to the effect that the troubles do not occur where *the conditions of design are proper.* Those conditions of design have fortunately been determined by the larger companies and the principal engineers operating this kind of apparatus. Those principles of design were not secured off hand or *a priori*, but have been somewhat of an evolution from experiences of the first few years in the application of the earlier apparatus in service. Looking at the subject in a broad way, any generator, or any motor, made by anybody, is not likely to follow these conditions of proper design. The requirements, therefore, for the successful operation of a synchronous motor, demand of the designer, the consulting engineer and the purchaser, a closer and different class of attention than is necessary for the induction motor. I am not at all taking the position that the synchronous motor will not work, or cannot work, or does not work; but I have endeavored to point out certain conditions of difference, mainly those in service, which have led to the large introduction, and I think the ascendancy, of the induction motor.

A number of times in the discussion, the starting current, that great bugbear in many minds in the consideration of the induction motor, has been brought up, but I have failed to see pointed out by any of the speakers anything to show that the synchronous motor would do better. What can be done with the synchronous motor? If a starting motor is used, or some other device, why, we have the same thing available for the induction motor, but usually the induction motor can itself do better than the auxiliary device could do. It has been noted that in some places the effect of starting the induction motor with load is to "kill" the system. What would the synchronous motor do under similar circumstances? It is pointed out by Mr. Stillwell that in a certain case, one type of synchronous motor, that is, a rotary converter, took some five times its full load current for starting without load. Even granting that the induction motor would do the same, it could do more than start its own armature, for it would in that case be developing more than its full load torque.

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The matter of efficiency in power has been referred to and attention is called to possible differences of a few per cent. There is something larger to consider than this, and that is the efficiency in service. If one class of apparatus gives assurance of less trouble in operation, less liability to accident, less shut-down in the circuits and service, that demands a considerable preference over one which may have liabilities to disaster, although it may have a little greater efficiency. It has been pointed out that the synchronous motor and the induction motor behave differently on lower voltages, that a lowering of voltage of 10 per cent. will lower the maximum capacity of the synchronous motor by 10 per cent. and that of the induction motor by about twice that amount. The criterion to settle a point of this kind is that of service. In which case, with which class of apparatus is there the most difficulty from this cause? And, where difficulty does occur, with which is the more serious? Another point may be made, which is referred to in my paper, in the comparison of the two motors. If the synchronous motor is overloaded its speed curve takes a vertical drop. If the induction motor is overloaded it comes down in speed slowly as it has torque at low speeds, thus making use of the stored energy in the system.

Dr. Perrine has made a few specific statements regarding the operation of some motors of large size. He has given certain facts, enough, I think, for me to identify the cases to which he refers—one, I think, a 400 h. p. and the other a 300 h. p. motor. He states that in one case, the 300 h. p. motor could not receive enough current to start a flour mill when operated by a generator of a little larger size, I think, 400 k. w. or such a matter. There are certain other facts there. One is that to start a flour mill requires a very large torque, as the parts of the flour mill get in position where it requires a very great effort to start them, so that a torque considerably greater than the normal running torque is necessary for starting a complete flour mill. Any motor would legitimately be allowed a fair current for starting. In this case I have not the figures exactly in mind. My best recollection is that the generator supplying this current was unable to give a current to the motor equal to, say, twice the full load current. The generator was one of a type with the saturated field, so that a very considerable field current is required for increasing voltage, and the exciter was doing the best it could as its belt was thrown off during the process of trying to give enough exciting current to the generator to start the motor. At reduced voltage and at a power factor of about 60 per cent. the generator could give an ampere-volt output which was only slightly above its normal rating. That is, the maximum that that generator could give was not double current, or three times the normal current, but it was equivalent to only a little more than its normal output, so that it would hardly be reason-

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able to expect any motor to receive from that generator enough current to start the flour mill. The induction motor was first designed for better running than starting conditions, which was not the most favorable for that service. The men were required to pull on the belt. If I remember correctly I was one of the men at a certain time. He states that some four friction clutches were used in the mill. He did not state whether these were in series or multiple, but probably they were in multiple for different sections of the mill. May I ask how many friction clutches would have been required and what starting conditions would have been required, if a synchronous motor had been used in that case? He referred also to a 400 h. p. motor. If I remember correctly it was the same firm which had bought this first motor and put it in the flour mill, and had had these various troubles, which was later to equip another mill. Did they leave the induction motor and buy the synchronous motor, or take anything else? No. They used the same kind of a motor for that second place.

I am not quite sure what the reasons are here in Buffalo, but I learned just a few minutes ago, however, that after a large use of synchronous apparatus in one of the stations which we are to visit this afternoon, the latest addition there has not been a synchronous motor but a large induction motor.

Lastly, this is not so much a question of theory as a question of fact. What is the experience with the motors of the two classes? I have given this subject pretty careful attention for a number of years back, and have tried to put this question to plants operating synchronous motors and induction motors—"Where troubles have occurred, of whatever kind, would they have been prevented if the other kind of motor had been used?" There may be accidents which cannot be prevented. They may occur through carelessness; they may be caused by short-circuit on the line. It may be that a momentery short-circuit or accident on one line has caused the system to shut down and it has taken a little while to start up. Could the trouble have been avoided, could the system have been more easily started, or would the effects have been more disastrous, if the other kind of motor had been used?

VICE-PRESIDENT DUNN:—I now extend the floor to President Steinmetz to close discussion on his paper and on Mr. Rice's paper, which he read.

PRESIDENT STEINMETZ:—Gentlemen, all I have to say is that I am very gratified with the reception of my paper, and I was very pleased to hear from our friends from the other side that some features dwelt upon in my theoretical paper had been observed in actual experience there, as they have been observed a number of times in this country.

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Regarding the second paper, of Mr. Rice's, I desire to draw your attention to one feature, and that is the tests at Kalamazoo at a voltage of 25,000 and 40,000. This is the first case which has come to my notice where the oscillagraph has been successfully used in actual service conditions of a transmission plant at so high a voltage as 40,000.

[Adjourned to Friday, Aug. 23.]

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Interior of Power House No. 1, Niagara Falls Plant.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 23d, 1901. President Steinmetz in the Chair.

THE ELECTRIC TRANSMISSION OF POWER FROM NIAGARA FALLS.

BY LEWIS B. STILLWELL.

I. Introduction.

The history of the Niagara Falls power plant is a demonstration of the ability of applied electrical engineering science to attain in commercial practice results predicated in large degree upon theory. In a most striking manner, it exhibits the fact that for nearly a decade electrical engineering has been established upon a basis as certain and permanent as other branches of engineering; that eight years ago—a long time in our profession—it was possible to so plan an electrical installation involving ultimately the transmission and distribution of several hundred thousands of horse-power that at the present time we can effect improvement only with respect to relatively unimportant details, the aggregate results of which, if adopted, would be hardly noticeable as affecting the cost of power. I think it safe to say that if the Niagara Falls Power Company to-day were facing the same problem which they solved in 1893 and should bring to bear upon it the same comprehensive and thorough-going methods which at that time characterized the work of its officers and directors, their solution, based upon all that has been learned up to the present time, would be so nearly identical with the solution which they adopted eight years ago that the resulting cost of power delivered to users would not be affected even to the amount of one dollar per kilowatt year.

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These facts are perhaps in no sense surprising to members of this INSTITUTE, but the general public, and even many men of broad intelligence and large affairs, unquestionably still have a feeling that electrical engineering is in large degree experimental, and that capital invested in electrical enterprises to day may vanish to-morrow by reason of some new invention. It is surely important to establish confidence in the certain and permanent character of adequate electrical engineering, and I shall ask you to consider the Niagara plant with special reference to two thoughts, viz., (1) How does the plant as it now stands completed differ from the plans contemplated in October, 1893, when the original contract for electrical machinery was closed; and (2) What has experience in the construction and operation of the first plant suggested in the way of further improvement? The history of the plant considered with these thoughts in mind constitutes a forceful reply to the statement so often made that "electricity is in its infancy," and should go far to establish confidence in the ability of electrical engineering science to predict with accuracy results that are reasonably certain to be realized in practice.

In saying that if the Niagara Falls Power Company in 1901 were facing the problem which they solved in 1893, the solution now would be substantially identical with the solution then, I am not saying that there has been no important improvement in electrical methods and machinery during the last eight years. Undoubtedly the art has advanced; methods of manufacture by reason of accumulated experience and improved facilities are far more satisfactory now than they were then. Our knowledge of theory, particularly the theory of alternating currents, is relatively far more complete, but progress in alternating current methods since 1893 has been in no sense revolutionary, and the time has long since passed when capital might reasonably hesitate to embark in well-considered enterprises depending for success upon a correct application of electrical engineering skill. It is a significant fact that the electrical machinery to be installed in the second power-house now under construction will differ from that now in use in power-house No. 1 with respect only to details of construction, relatively unimportant, while nearly every constituent part of the hydraulic equipment of the new plant will be materially and even radically different from its predecessor.

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It has been said that electricity as a science is only less exact than astronomy, but the fact that a science is exact, by no means implies that there is but one reasonable way of applying it to the solution of an engineering ploblem. Naturally, in electrical engineering, as in other departments of human endeavor, several roads often lead to practically the same goal, and were a Niagara problem to be presented for solution to-day to the members of this INSTITUTE, I have no doubt that the plans proposed would exhibit sufficient variety to remove all fear that practice is liable to become so "standardized" as to leave no room for originality, new ideas and consequent progress, but I imagine that the plans proposed, while varied, would be by no means so widely divergent as they would have been in 1893. To the business man without technical training who may venture to read the discussion of a subject like this by an engineering society, the natural divergence of individual views expressed with respect to frequency, potential and all the rest must convey the impression that there is no such thing as established lines of practice, but when these differences of opinion are expressed in concrete units of cost it is apparent that considerable variety of detail in plan and construction may be consistent with attainment of the same practical result.

II. THE PROBLEM PRESENTED.

The wisdom or unwisdom of the plans adopted in 1893, upon which we now have the additional light of eight years' extraordinary activity in both theoretical and practical work, must be judged with reference to the conditions and requirements of the market for power then assumed rather than with reference to the requirements of the market as now actually developed. It was expected in 1893 that a very large proportion of the power developed would be utilized by motors in mill and factory work. With regard to the local use of power at Niagara, this anticipation has not been realized and even in Buffalo more than half the Niagara power used is utilized in operating the street railway and lighting systems.

In a descriptive memoir which I drew as Electrical Engineer of the Westinghouse Company, and which was submitted to the Cataract Construction Company under date of February 6, 1893, my understanding of the problem presented was stated as follows:

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"We are to lay out a system that will enable you to take energy at the upper end of vertical shafts making 250 R. P. M., each shaft delivering 5000 H. P., and to deliver in saleable and reliable form the largest practical and economical percentage of this energy; 1st, within the limits of Cataract City, distance not exceeding two miles; 2d, at the northern boundary of the City of Buffalo, 3rd at more distant points, *e. g.*, New York and Chicago.

In each of the above cases energy is to be delivered in form available for:

1. Power purposes.

(a) General mill and factory work, pumping stations, etc.; units of from 10 to 1000 H. P.

(b) Operation of street railways; units of from 100 to 1000 H. P.

(c) Miscellaneous work in factories, mills, the operation of elevators, printing presses, etc.; units 1 to 25 H. P.

2. Lighting purposes.

(a) Arc lights.

(b) Incandescent lamps.

3. Electrolytic purposes.

It is proposed to ultimately locate twenty-five 5000-H. P. turbines at the power-station on the American side of the river, and upon the Canadian side of the river an as yet undetermined number of units of equal size. The distance between the power-stations, by way of the Suspension Bridge is 2½ miles, and it is desired to provide electrical connection between the stations so that the generating apparatus in one station may in time of emergency be substituted for that in the other.

While the above stated capacities are to be ultimately installed, the immediate requirements are limited to three generating units of 5000-H. P. each, with whatever apparatus may be needed in connection therewith, first, to transmit and distribute energy within the limits of Cataract City; second, to transmit energy to a sub-station located at the northern boundary of Buffalo.

For electrolytic and power purposes the capacity of at least one machine will soon be called for at the manufacturing center, Echota, situated 7000 feet from the power-station on the American side of the river within the limits of Cataract City; from 200 to 300 H. P. will be needed for the operation of an electric freight and passenger railway, extending from the power-house by way of Echota to a junction with the New York Central Railway, situated near the northeastern limits of the new city of Niagara Falls.

It is proposed to employ one or two generators to supply power to a sub station at the northern limit of Buffalo. The amount supplied will depend upon the market for power, and the system selected must be such as will admit of ready and symmetrical increase with the growth of the demand. As stated by Mr. Adams, the principal purposes for which power is now used in the city of Buffalo, with the approximate amounts for each, are:

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Pumping	4,060 H. P.
Operation street railways	3,000 H. P.
Arc lighting	3,500 H. P.

In addition to this about 1,000 H. P. is used to supply incandescent lamps, and there is also a considerable amount of power used for miscellaneous purposes in factories and mills.

The ability to reach more remote markets for power,—as, for example, the cities of New York and Chicago,—will depend upon the practicability of properly insulating the conductors used for the transmission of currents. Recent progress in this direction has been such as already makes our available radius of transmission greatly exceed the distance between the power station and the city of Buffalo, and it is desirable that the system selected should be such as will lend itself to future transmission over very great distances.

In considering the above requirements we note, first, that the conditions impose the following as necessary characteristics of the system:

1st. Alternating currents for transmission.

2nd. Direct currents for electrolytic work.

3rd. Direct currents for street railway purposes.

For general power purposes, and for arc and incandescent light, the conditions are not restrictive, and we may use either alternating current or direct current. But while both alternating and direct currents are needed, it is in the highest degree desirable that the system should be so laid out as to admit uniformity in size and type of generators. This feature in an installation is of the greatest value, as it allows ready substitution of one generator for another when for any reason such substitution becomes desirable. It implies also uniformity in auxiliary station apparatus, and a symmetry of system which is invaluable in the practical operation of the plant."

III. The System Adopted.

The system chosen to meet the complex, and, up to that time unprecedented requirements was the alternating current system using two-phase alternators wound for 25 cycles per second and 2,200 volts. It was adopted as the result of a most comprehensive and pains-taking investigation conducted under the personal direction of Mr. Edward D. Adams, President of the Cataract Construction Company, assisted at every step from the inception of the enterprise by Dr. Coleman Sellers as his chief engineering adviser. It was adopted notwithstanding the fact that some of the greatest scientists of the day advised against the use of alternating current and in favor of direct current. That the

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directors of the company in 1893 selected a system substantially identical with that which they would undoubtedly choose to-day to meet a similar problem is due in very large degree to the great ability and conscientious care of that grand old American engineer, Coleman Sellers, of Philadelphia, himself not claiming special knowelge of electricity, but possessed of vast experience in engineering science in many fields and excellently qualified to judge both electricians and their works.

The Cataract Construction Company, from the time when the directors and Dr. Sellers seriously began their study of the problem of utilizing Niagara power in 1889, to the time of closing the contract with the Westinghouse Electric Company, of Pittsburg, Pa., for the first three alternators, arrived at six important decisions with respect to engineering practice. These decisions were: (1) to use a central power station and a system of electrical power distribution, "as the chief means of distributing the power, though perhaps not the only means;" (2) to adopt a uniform system for both local and long distance transmission; (3) to use the alternating current system; (4) to reject the three-phase system; (5) to adopt a frequency of 25 cycles per second; (6) to use alternators wound for about 2,000 volts and step-up transformers for transmission to points not economically reached by the potential generated.

The decision to use a central power station developing power in large amounts by turbines located in a limited number of large wheel pits and to distribute power electrically instead of adopting an exclusively hydraulic development as generally used prior to that time in the development of water power for manufacturing purposes, was undoubtedly wise. To-day in new plants the utilization of water power is almost invariably accomplished by means of electrical distribution.

To adopt the alternating and not the direct current system was also undoubtedly wise. In 1893, however, there were still many who believed that the direct current system possessed superior advantages, but the development of the art of transmitting and distributing power has long since practically settled this question. There is nothing in the work of Thury, or others, who have attempted to utilize continuous currents at high potential for long distance transmission that would lead us to question the superiority of the alternating current system for long distance

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transmission of power. The transformer is the key to the solu tion of this problem which those who had done most in the development of continuous current apparatus in 1893 were generally ready to admit could not be solved by continuous current methods.

The wisdom of the decision to reject the three-phase system is at least open to question. This decision was reached by the directors of the Cataract Construction Company in May, 1893. I am on record prior to that time, and in fact as far back as 1889, in advising the use of the two-phase system, but from present knowledge I believe that the decision to reject the three-phase system in May, 1893, was a mistake. At that time Charles F. Scott's clever invention of the method of winding and connecting transformers to secure three-phase currents from a two-phase source had not been announced and but for that invention it is my opinion that the additional cost of conductors required by the two-phase system would to-day turn the scale in favor of the three-phase plan. Under the conditions existing at Niagara, however, where single phase power is required in a number of cases, the two-phase arrangement possesses a substantial advantage in the entire separation of phases and the convenient balancing of the load, and were a new Niagara problem to be presented to-day with conditions precisely such as are met by the existing plant, as we now have the means of obtaining three-phase currents for the more distant and therefore more expensive transmission, while using for local distribution either single-phase or two-phase circuits, I should still incline to the use of two-phase alternators.

As regards the frequency chosen, viz.: 25 cycles per second, experience since 1893 has demonstrated the wisdom of its selection. This frequency is to-day more generally used in America in electrical distribution for power purposes than any other. Personally, I consider 30 cycles preferable, but at Niagara it was not possible to adopt this frequency for the reason that the speed of the turbines had been fixed at 250 revolutions per minute before the question of frequency was seriously considered. A 16-pole dynamo at 250 R. P. M. will produce 33⅓ cycles per second and a 12-pole dynamo twenty-five cycles per second. There were difficulties in the way of winding a 14-pole machine for two-phases, and after very careful consideration of the relative advantages of 25 cycles and 33⅓ cycles the former was chosen.

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My principal reason for believing that a frequency of 30 cycles per second is preferable to 25 cycles per second is that 110-volt incandescent lamps of 16-candle power or more, when supplied at that frequency from practically any commercial alternator, are free from any suspicion of fluctuation in candle power due to reversal of current, while at 25 cycles such is not the case. At Niagara, the town of Echota is satisfactorily lighted by incandescent lamps using 25-cycle currents, but this result is somewhat assisted by the fact that the potential wave of the Niagara alternators is flatter than a sine curve. A great deal depends upon the form of the E. M. F. wave, although I do not remember having seen this point mentioned in any of the published discussions of this subject. If the wave be pointed or peaked, *i. e.*, if the ratio of maximum to mean value of the E. M. F. during a half cycle materially exceed the ratio of these quantities in a sine wave, incandescent lamps will show visible fluctuation at frequencies considerably higher than is the case if a flattened wave be used. Of course a 110-volt lamp will show fluctuation under conditions when a 50-volt lamp will show none and presumably 220-volt lamps are still more sensitive, although I have never tested this experimentally. I have found no reason, therefore, to modify the opinion first formed in 1890, that for plants in which the supply of power is the principal object, 30 cycles, which, with absolutely satisfactory results, permits also direct supply of incandescent lamps, is the best frequency.

The alternators were wound to deliver 3,730 killowatts at any desired potential not less than 2,000 volts and not exceeding 2,400 volts. My intention in thus defining the limits of working potential was to provide for drop in transmitting and distributing circuits using 2,000 volts as the general potential delivered to users of the power and allowing in the generators for an increase of potential at terminals amounting to 20%, which amount I considered might be necessary in undertaking very distant transmission at some future time. In some way which has never been clearly explained, the officers of the Cataract Construction Company apparently interpreted the phrase "from 2,000 to 2,400 volts" to mean 2,200 volts and the apparatus used by the first electrical tenant of the power company, viz.: The Pittsburg Reduction Company, which apparatus was supplied by the General Electric Company, was wound for 2,200 volts.

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In this way, the delivered potential at Niagara, and subsequently for reasons of uniformity in Buffalo, was fixed at 2,200 volts. The reasons for choosing a potential of about 2,000 volts are indicated by the following quotation from a letter which I wrote October 2, 1893:

"We should mount the fields of the generators upon the extended turbine shafts and should wind the stationary armatures to deliver current at a potential of from 2,000 to 2,400 volts. This potential is well adapted to your work in Cataract City. It is sufficiently high to secure good economy in the system of distribution, and it is not so high as to impose special difficulty and danger in the insulation of the circuits and the manipulation of the switching devices. Motors may be operated from circuits conveying current at this potential without the use of step-down transformers.

For transmission to Buffalo and other distant points, we should advise a high potential, say 10,000 volts, obtained by step-up transformers. If possible, these transformers should be so designed and the units so selected as to permit an increase in potential of the long distance transmission circuits, say to 20,000 volts, as soon as experience gained in transmission at 10,000 volts may indicate the practibility of insulating the circuits for the higher potential.

In our memoir of February 6, we recommended 800 volts for the potential in the distributing circuits in the vicinity of the city of Niagara Falls. We were largely guided then, as now, by the consideration that the potential selected should be the highest which may be safely employed at the motors without the interposition of step-down transformers. We assumed, however, at that time that there would be a very large proportion of small motors, as is the case in the hydraulic plant in Geneva, Switzerland, but we are now advised by your engineers that by far the larger part of the power called for in the vicinity of the Falls will be in units of not less than 25 H. P. In such motors, it will generally be safe to employ 2,000 volts."

As I have said, the alternating current system rested, and still rests, upon the transformer, which, having no moving parts, yet enables us at will to transform from low potential to high potential and the reverse, utilizing extremely high, and therefore economical, potentials for transmitting power over long distances while employing moderate and easily handled potentials, both in the dynamos which produce the electricity, and in the motors and lamps which utilize it in markets perhaps many miles distant.

The transformer of Gaulard, which was adapted to constant

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current circuits, was brought to the United States by Westinghouse, and was there primarily developed by Stanley and Shallenberger, who early perceived the much greater usefulness of closely regulating transformers adapted to constant potential circuits, and turned their efforts in that direction.

The polyphase motor, as invented by Tesla, occupied no such place in practical engineering work in 1893 as it does to-day, and the same is true of the rotary converter. Tesla and Scott in America, and Dobrovolski in Berlin, had been gradually improving the motor until at the time named it was really a practical and successful machine under certain conditions, but it had not been widely introduced into commercial use, and the enthusiastic hopes aroused when the Tesla invention was first announced in 1888, had not been realized by the public, nor were its possibilities and limitations realized even by electrical engineers, except those who were actually in touch with the work of experimental development.

That the Cataract Construction Company displayed courage as well as good judgment in adopting alternating currents in 1893, and that the subject of alternating current motors was little understood by engineers outside of certain factories at that time is well illustrated by the fact that one of the consulting engineers, of the Cataract Construction Company in a paper on "The Electric Transmission of Power from Niagara," read before the British Institution of Electrical Engineers, November 9, 1893, attaches great weight to the alleged possibility of converting continuous current motors into synchronous alternating current motors by the addition of rings. On page 503 of the Journal of that society he says:

"In concluding my remarks upon low frequency I must again repeat that, from a purely practical and commercial point of view, one of the great advantages lies in the fact that for any special purpose for which a motor is required any ordinary direct current motor may be altered so as to act as a synchronizing alternating motor at a very small expenditure of time and money."

The author apparently had in mind the use of an extremely low frequency, but the fact that he seriously believed in the possibility of converting into commercially effective alternating current motors the general run of continuous current motors is enough to indicate the vague ideas then generally prevalent with regard to alternating current motors.

As regards rotary converters, the function of which is the conversion of alternating currents to continuous currents, thus

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rendering available for electrolytic work and for operation of continous current motors power transmitted in the form of alternating currents, even less was generally known. Schuckert exhibited small machines of this character at the Frankfort exposition in 1890, and in America, Bradley and others had been engaged with more or less success in developing commutating machines of various types. During the autumn of 1892, the Westinghouse Company invited the Cataract Construction Company to examine two 150 H. P. converters and on January 19, 1893, Dr. Coleman Sellers and the late Prof. Henry A. Rowland carefully tested these machines in Pittsburg. The machines were simply four-pole, continuous current, 500-volt, generators fitted with ring collectors. Continuous current at 500 volts was delivered to the first machine, which, operating as a converter, delivered alternating current at 25 cycles per second to a second machine, which, in turn, operating as a converter, delivered a continuous current through a non-inductive resistance. The energy supplied to the first machine and the energy delivered by the second machine were measured and compared, the difference representing the sum of the losses in the two machines. The approximate efficiency of each machine was calculated by dividing the output of the second machine by input of first machine and extracting the square root of the quotient. The efficiency thus obtained for various outputs of the second machine was as follows:

Output of second converter.	Approx. Efficiency of each converter.
20,560 watts	78.9%
57,270 "	90.%
117,970 "	91.5%

These results will compare favorably with those that are now obtained in machines of similar output.

In the autumn of 1892, as Electrical Engineer of the Westinghouse Company and in co-operation with Albert Schmid, O. B. Shallenberger, Charles F. Scott and B. G. Lamme, I planned an organization of electrical apparatus to be exhibited at the World's Fair in Chicago the following year for the purpose of illustrating the possibilities of electric power transmission. The apparatus was constructed and was shown in operation in Chicago from May to November, 1893. Figure 1, which is photo-

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graphically reproduced from a descriptive publication which I prepared at that time, shows that this exhibit comprised every essential feature which is to-day utilized by the plant of the

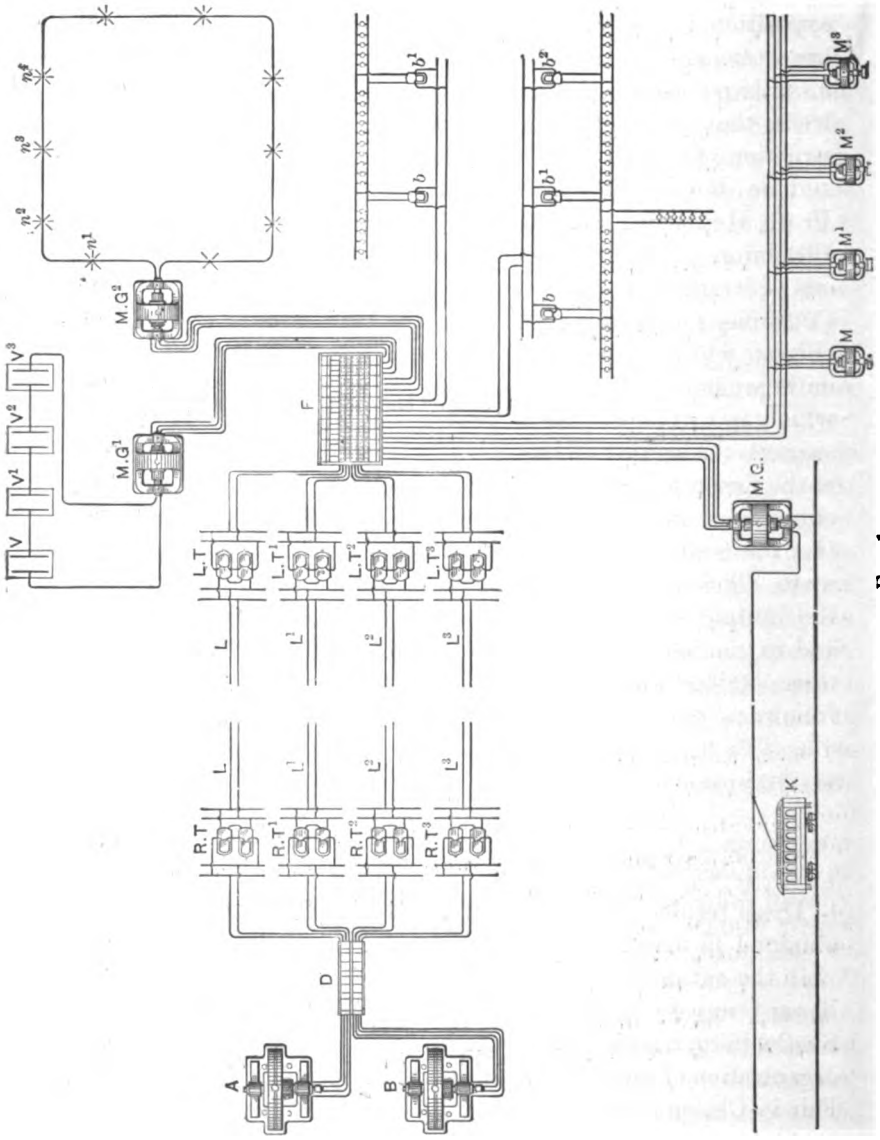

FIG. 1.

Niagara Falls Power Company except the two-phase three-phase connection of the transformers. In the diagram, A and B are alternators; D the power-house switchboard; R T, R T′, etc., rais-

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ing transformers; L, L′, etc., transmission circuits; L T, L T′, etc., step-down transformers; F the distributing switchboard in a substation; M G the motor generator or converter receiving alternating current and delivering continuous current for the operation of a street railway; M G′, and M G² converters delivering continuous current, respectively, to electrolytic plants and to direct current arc lamps, M M′, etc., polyphase alternating current motors, and *b b′*, etc., step-down transformers supplying incandescent lamps. In the plant exhibited at Chicago, one 375 K.W. two-phase alternator, one 375 K.W. converter delivering continous current at 550 volts, one 60 H. P. synchronous motor and a number of smaller machines, including induction motors up to about 15 H. P., were shown.

The frequency was 30 cycles per second, the transmission potential 10,000 volts. A 60 H. P. direct current motor using current from the rotary converter was used to drive an Ingersoll-Sargent air compressor. The 60-H. P. synchronous motor was shown in operation. Incandescent lamps were supplied through transformers and arc lamps by continuous current obtained from a rotary converter.

I deem it proper to make this record in this place not only as a matter of justice to my associates and myself who did much work from 1888 to 1893 in evolving the system adopted at Niagara, but also to establish a fact which is of interest to the INSTITUTE, viz.: that while the Niagara plant embodies the ideas of many men, British and Continental as well as American, the evolution and development of each of the important parts of the system as used at Niagara and the aggregation of these parts into a working plant, accurately adjusted, easily controlled and delivering power to-day for a multiplicity of purposes in Western New York was American, as the far-sighted business enterprise which invested very large capital in a project depending for success upon many factors not tested by experience was also American.

In the descriptive memoir of February, 1893, from which I have above quoted, the application of the system proposed to a territory already occupied by competing steam-driven plants was pointed out as follows:

"Your two-phase alternating current, delivered at high potential at the northern boundary of the city, must be reduced by transformers to a potential that may be safely carried on local

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distributing circuits. Your company, or the company to which you will sell current delivered in Buffalo, will desire to make a proposal to the city looking to the substitution of motors for the pumping engines now in use for this purpose. The system offers the two-phase synchronous motors of large capacity—probably of capacity corresponding with that of the engines now installed. These machines will be self-starting, and, using ring collectors in place of commutators, their construction is such as will make maintenance a minimum.

"You will also desire to supply power for the operation of the street railway systems of the city. Our system makes it possible to approach the street railway companies with alternative propositions; first, to furnish motors to drive generators in place of the engines now in use; second, to substitute revolving transformers for both engines and generators; that is to say, to put in place of one engine and one generator, a single machine operating at an efficiency of from 92 per cent. to 95 per cent., depending upon its capacity. The entire steam and electric plant now installed can be held in reserve or sold.

"As regards the arc lighting of the city, you can also make alternative propositions; first, to substitute synchronous motors for engines now in use; second, to install rotary transformers, making a total change in the arc lighting system. In all probability the first of these will be the practicable method at the present time; but the direct and economical method of using the energy of your water power to supply arc lights in Buffalo will ultimately involve a total change of system, and the abandonment of the arc lighting apparatus now used.

For incandescent lighting, the system also offers alternative methods; first, the substitution of synchronous motors for engines; second, a change of system, and the use of large transformers reducing potential from local primary distributing circuits to 50 or 100 volts in secondary circuits. While it may be necessary for a time, owing to the fact that several different interests are concerned, to use the electric energy transmitted from the Falls to supply motors driving existing electric generating apparatus, the system which we have laid out looks to the future, and will lend itself at any time when commercial considerations may permit, to a broad gauge solution of the problem of utilizing the energy of Niagara Falls to supply power and light to the city of Buffalo in the most direct, efficient and satisfactory manner."

The high potential current now actually delivered to transformers in the terminal house near the northern boundary of Buffalo is three-phase and not two-phase as anticipated in the memoir referred to. The change, which of course implied a very marked reduction in cost of transmitting and distributing circuits, was made possible a few months later by the inven

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tion of the two-phase three-phase connection of step-up transformers, without departing from the use of two-phase alternators.

A considerable number of synchronous motors are to-day in use in Buffalo, but they are three-phase and not two-phase motors. The street railway systems of the city are operated by power supplied through converting machinery as described in the memoir.

The arc lighting of the city is accomplished at present by the first of the two alternative methods outlined in the memoir, viz.: the use of synchronous motors in place of engines.

Incandescent lighting in Buffalo is supplied with power in large part by synchronous motors driving constant potential, 60-cycle, two-phase alternators, and, to a less extent, by direct current obtained from rotary converters.

IV. The First Three Alternators as Planned and Constructed.

The general mechanical features of the alternators, *i. e.*, the external revolving field with inwardly projecting field poles surrounding a centrally located and stationary armature, were proposed by Prof. Forbes. For a 5,000 H. P. alternator having a vertical shaft and operating at the very high speed of 250 R. P. M., no better form from a mechanical standpoint has ever been produced. The type, however, is not well adapted to a high potential winding nor to the attainment of very close regulation under conditions of high speed and low frequency. Considerations of mechanical safety limit the normal speed of the periphery of the revolving field to something less than two miles a minute, and when the necessary thickness of ring and length of field pole are subtracted from the radius thus fixed, the limiting diameter of the armature comes out at something like nine feet. A frequency of 25 cycles per second implies 12 poles, and the armature reaction is necessarily so powerful as to render impossible the attainment of 6% or 8% regulation as is now common in slow speed alternators of output comparable to that of the Niagara machines. The small diameter of the armature also limits the space available for insulation and so limits the potential for which the machine can be wisely wound. As the art stands today, a distributed or bar winding for 5,000 volts or an open slot coil winding for 10,000 volts could perhaps be adopted in a machine of this type and size,

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without unduly reducing the factor of safety in commercial operation, but these figures cannot be attained without reducing the factor of safety below the point attained in the 2200-volt machines now in use.

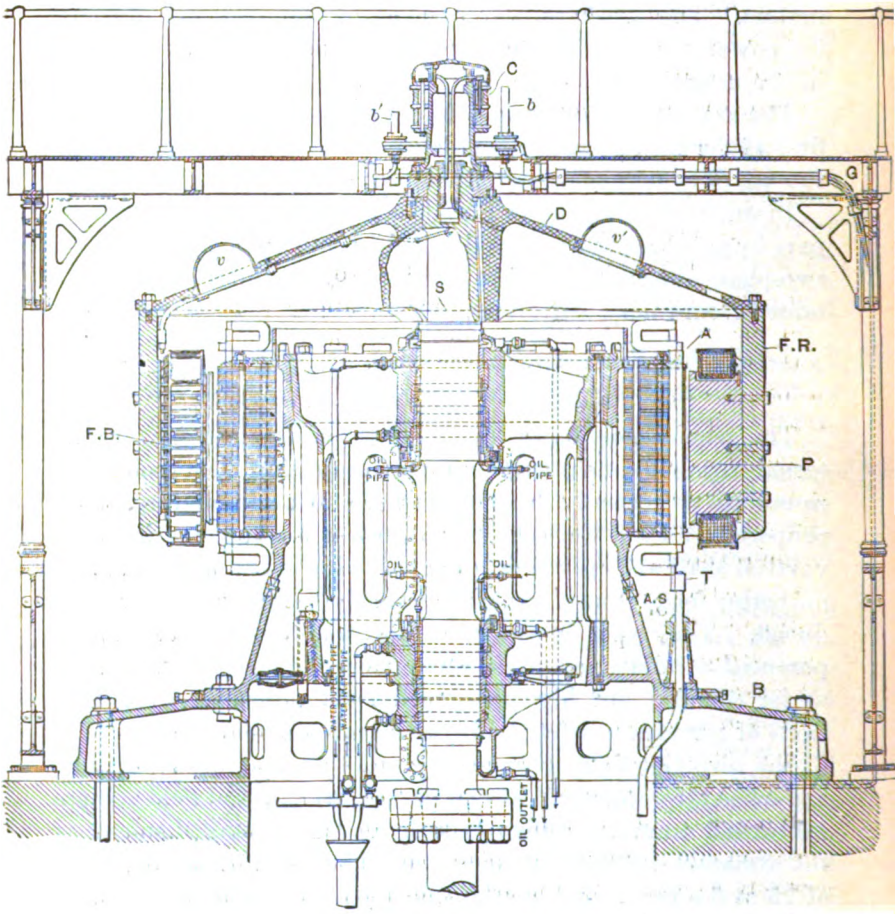

FIG. 2.

When it was decided to wind the Niagara alternators for a potential of 2,000 to 2,400 volts, it was expected that a very large part of their output would be utilized by alternating current motors located within two miles of the power house. This potential, therefore, was chosen with reference not only to a high factor of safety in the insulation of the alternator armatures but also with

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reference to the insulation of cables and motors of 25 H. P. and upward, which the company expected to supply without the interposition of step-down transformers. For the conditions of the commercial demand then expected, I believe no better potential could have been chosen.

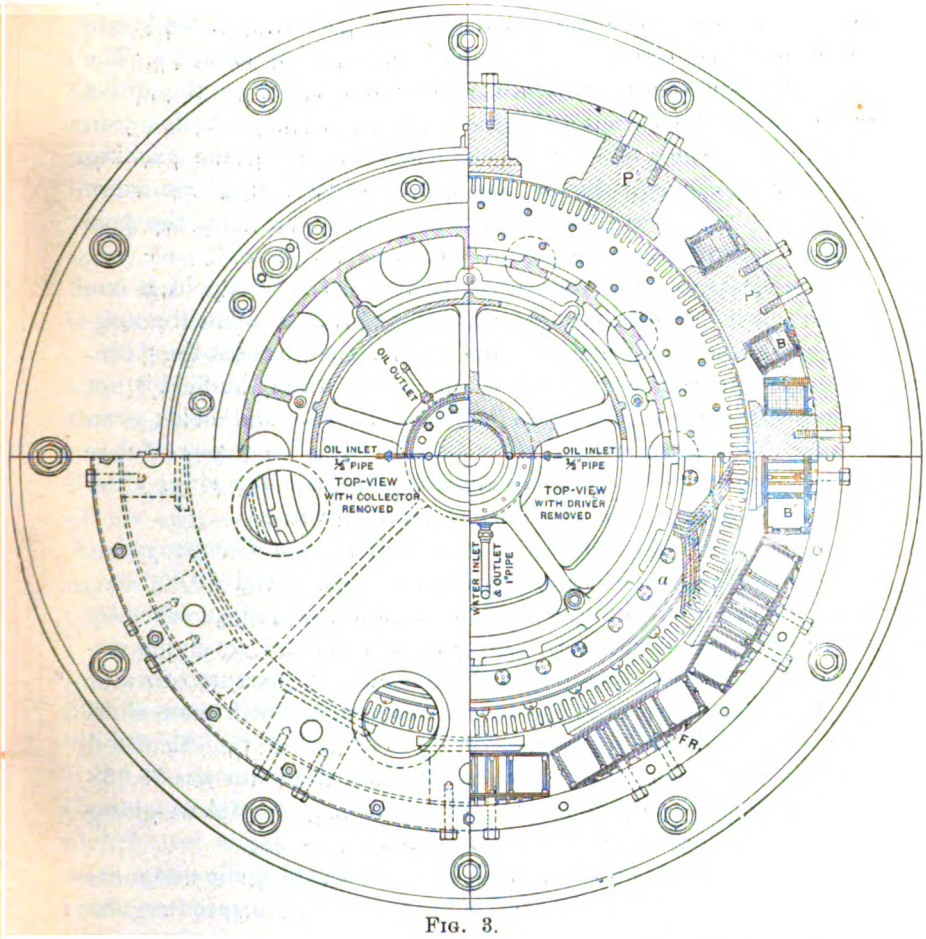

FIG. 3.

Figures 2 and 3 showing vertical and horizontal sections of the alternator, illustrate the construction of the first three machines.

Referring to the vertical section through center line of shaft shown in Fig. 2, A is the stationary armature, secured in place by the armature support A S, which in turn rests upon the bed plate B.

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One of the four terminals at which the current from the armature is delivered to the cables leading to the switchboard is shown at T. Of course since the armature is stationary, no ring collectors or brushes for the alternating current are needed. The revolving element consists of the shaft, S, carrying the driver, D, the field ring, F R, the steel pole pieces, P, and the collector, C, by means of which the current delivered from the exciters to the brush-holders and brushes, b b', is conveyed to the field bobbins, F B. The bridge which spans the machine and gives access to the direct current collector rings and brushes is supported by hollow iron columns through which the conductors conveying the exciting current are carried. In the horizontal section through armature and field, A is the armature, F R the field ring P, P', etc., the pole pieces, and B, B', etc., the field bobbins.

The clearance between the armature and the field poles is one inch. It is interesting to note that in these alternators the magnetic attraction between armature and field acts against the "centrifugal force" and not with it. Of course when the field is not charged there is no attraction between armature and field; even with full charge the magnetic attraction is not very powerful as compared with the force which tends to burst the ring. The point, therefore, is not of any great practical value.

It was specified by the Cataract Construction Company that the weight of the revolving part should not exceed 80,000 lbs., this limitation resulting from the general arrangement whereby practically the entire weight of turbine shaft and revolving element of alternator is supported by the upward pressure of water in the wheel case. As showing the care with which these alternators were designed, it is interesting to note that the calculated weight of the revolving element of the first alternator was 78,958 lbs., while the actual weight, as determined by careful weighing of the several parts before shipment, was 78,600 lbs.

Another specification based upon requirements of the designers of the hydraulic machinery and having reference to speed regulation provided that "the revolving part is to have a fly-wheel effect which when measured by the pounds times the feet per second squared shall be over 1,100,000,000." The calculated fly-wheel effect obtained for each of the first three alternators is 1,274,000,000.

The Field Ring. A serious limitation in designing the alternators was imposed by the high speed adopted, which had been

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chosen apparently with reference to the design of the turbines and without full consideration of the design of the alternators. The normal speed specified was 250 R. P. M., but the possible run-away speed at which the alternators must be capable of revolving without danger of bursting the ring was fixed at 400 revolutions per minute. The calculated maximum strain in the ring at 250 R. P. M. is 5,052 pounds per square inch of section, the elastic limit and ultimate tensile strength of the material used being, respectively, about 50,000 and 82,000 pounds per square inch. At a speed of 400 R. P. M. the strains would approximate 12,500 pounds per square inch—*i. e.*, the factor of safety would still be 4. Any increase in diameter would of course increase peripheral speed, and as it was deemed unwise to work under any conditions with a factor of safety less than 4, the outside diameter of the alternator was fixed at 11 feet 7⅛ inches. The peripheral speed at 250 R. P. M. is therefore about 9,300 feet per minute.

When the first drawings of the Niagara alternators were under way it was not known, at least to the writer and his associates of the engineering staff of the Westinghouse Company, that the magnetic permeability of nickel steel was sufficiently high to justify its use in the construction of the field rings. The specification of the engineers of the Cataract Construction Company, dated August 23, 1893, and covering an alternator similar in general mechanical form to that finally adopted referring to the field ring, called for physical characteristics as follows:

"It must also have a tensile strength of not over 56,000 or under 50,000 lbs. per square inch, with an elongation of at least 30% between lines on specimen, the distance between lines being not less than twelve times the thickness of the specimen."

At the time when the first tenders were submitted to the Cataract Construction Company the magnetic qualities of various nickel steel alloys obtained from the Bethlehem Iron Company were undergoing investigation at Pittsburg, and before the contract was placed by the Cataract Construction Company it had been ascertained that nickel steel containing about 3¼% nickel possessed extremely high permeability in conjunction with great strength and ductility. The Westinghouse Company, therefore, recommended the substitution of the use of nickel steel field rings, and although the change involved an increase of more than 20% in the cost of the alternators, it is interesting to observe, as indicating the thorough-going manner in which the Cataract

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Construction Company carried out its work, that the better material was adopted without a moment's hesitation, notwithstanding its high cost.

The rings of the first ten alternators were forged at the works of the Bethlehem Iron Company, South Bethlehem, Pa. Briefly, the process is as follows:

A nickel steel ingot, 54″ in diameter at the bottom, 197″ long and weighing about 120,000 lbs., is cast solid and compressed by hydraulic pressure when fluid and during solidification. A block of the required weight is then cut from the ingot and a hole about 15″ in diameter is bored through its longitudinal axis. The cylinder thus formed is brought to a forging heat and expanded on a mandril under a 14,000-ton hydraulic press. After forging, the ring is carefully treated, to obtain the physical qualities desired, and is then bored and turned. Samples taken from the edges of the ring before it was turned to its final proportions were tested for ultimate tensile strength, elastic limit and elongation, with the following results:

Sample number.	Tensile strength measured in lbs. per sq. inch.	Elastic limit measured in lbs. per. sq. inch.	Elongation in 2″ measured in percentage of original length.
1	82,915	53,560	27.05
2	81,110	47,230	25.75
3	82,140	49,280	22.5

Samples similarly obtained were used to determine permeability. These samples were shaped into the form of cylindrical bars $\frac{5}{8}$″ in diameter and $7\frac{1}{8}$″ long, the Thompson form of permeameter being used.

Three samples were taken from the edge of each ring, as shown in Fig. 3 A. It will be noted that the axis of two of these samples is parallel to a tangent to the ring while the axis of the third is at right angles to that of the others.

A very interesting measurement of the permeability of the field ring, was made by magnetizing an entire ring by passing a known current through a coil wound about the ring, varying this known current in measured time and determining the resulting magnetization by measurement of the E. M. F. induced in a second coil, also wound about the ring. The E. M. F. induced in the second coil depends upon the number

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of turns and the change in the induction through the coil in a given time. Thus if 1,000 lines of induction are taken from the coil in one-tenth of a second a certain electromotive force will be produced. If there is a continuous change of say 1,000 lines each one-tenth of a second for a certain length of time there will be a uniform electromotive force induced during this time. If a given change in induction be made in half the time, the electromotive force produced is twice as great during the shorter period. The ordinary procedure in laboratory measurements of permeability by this method is to wind a ring a few inches in diameter

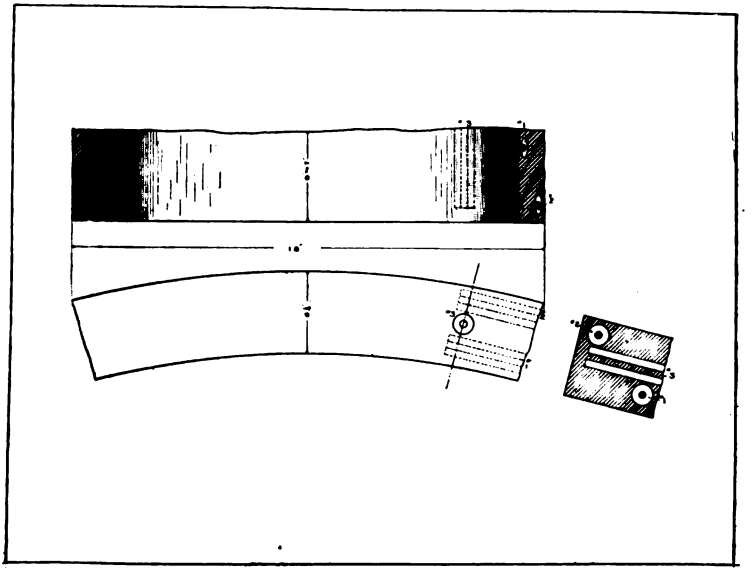

FIG. 3 A.

with two coils, to produce very sudden changes in a magnetizing current through the first coil and to determine the resulting electromotive force in the second coil by means of a delicate ballistic galvanometer which is adapted for measuring the sudden impulse in the secondary circuit.

The length of time required for making definite changes in the magnetization of a ring 11 ft. in diameter and weighing 27,000 lbs. is so great that the ballistic method of measuring is impracticable. The method adopted after several were considered was to change the magnetizing current slowly and at such a rate as to produce a

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fairly uniform rate of change in the magnetization of the ring. This produces a uniform electromotive force in the secondary circuit which can be measured by an ordinary voltmeter. The measurement of the electromotive force determines the number of lines of induction added to or subtracted from the ring per second, and this multiplied by the time in seconds determines the total change in induction during a test. The ring was magnetized strongly in one direction, and the current was then reduced, reversed and increased in strength until the ring was again magnetized to the original strength, but in the opposite direction. The total change in induction during the test was therefore twice the induction in the ring in its initial or its final condition. The instruments used in the measurement were an ammeter for measuring the current in the primary circuit, a voltmeter and a stop-watch.

The magnetizing coil was wound uniformly around the entire ring and consisted of 448 turns about one inch apart. The resistance of the circuit was about two ohms. The current was supplied by a direct current generator, and suitable arrangements were provided for varying the strength of the current and reversing its direction. A secondary coil of 30 turns was wound between the turns of the magnetizing coil at one part of the ring. This coil was connected directly to a Weston milli-voltmeter reading from .0001 to .1 volt.

A current of 100 amperes through the primary circuit was taken as a starting point for the measurements. The current was reduced at such a rate as to give a secondary electromotive force of about .04 volts. The current was at this rate reduced to zero, which required about two minutes, and was then increased to 100 amperes in a reverse direction. The change of induction per second required for giving .04 volt multiplied by the number of seconds between the positive and the negative magnetization gives the total change in induction during the test, which is twice the induction corresponding to 100 amperes. Inductions corresponding to different magnetizations could be determined by similar measurements with other current strengths. In the tests, however, readings were made upon the ammeter and voltmeter simultaneously at intervals of about ten seconds, and intermediate points between the two extremes were determined for plotting in a curve. It was very difficult to keep the secondary electromotive force exactly constant, but the result of a number of tests

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showed that no great error was introduced on this account, and that the average results were practically correct.

The permeability to be determined is the relation between the induction in the ring, measured by means of the voltmeter and the stop-watch, and the magnetizing force required to produce it, which is determined by the measurement on the ammeter multiplied by the number of turns. The electromotive force in the secondary coil when the induction through the coil is varying at a uniform rate is proportional to the number of turns, and the change in the number of lines of induction per second. The total change in induction during such a test is therefore found by determining the change per second by the voltmeter, and multiplying this by the time. The results of the measurement, plotted in the form of a B H curve, are shown in curve E, Fig. 4.

The measurements by the permeameter are also given in Fig. 4, in which curves A and B are, respectively, B H curves for wrought iron and cast iron, as determined by Hopkinson, using the ballistic method; C is the B H curve of nickel, as determined by Ewing; D the mean B H curve of the samples of nickel steel cut from the edge of the ring of the second Niagara alternator as determined by permeameter method and E the B H curve of the entire ring, as determined by the method above described.

It is to be noted that the curves by the two methods agree closely at low inductions, but differ at higher inductions, the ring method showing the higher induction. The sources of error at high induction in the permeameter due to error in estimating the length of the magnetic circuit, and in the leakage of magnetic lines from the sample near the point of contact with the yoke, tend to account for this discrepancy. The fair agreement between the two methods of measurement is of especial interest, as the measurements in one method are of force and current made by a spring balance and an ammeter, and in the other method measurement of electromotive force, time and current made by a voltmeter, a watch and an ammeter.

Field Poles and Winding.—The field poles are mild open-hearth steel castings. Their permeability is practically equal to that of the field rings. The field winding of the first three alternators as originally planned consisted of copper conductors of rectangular section about equivalent to one No. 0 wire B. and S. gauge. These conductors were covered with the usual cotton insulation and the coils were inclosed in ribbed brass boxes, from which

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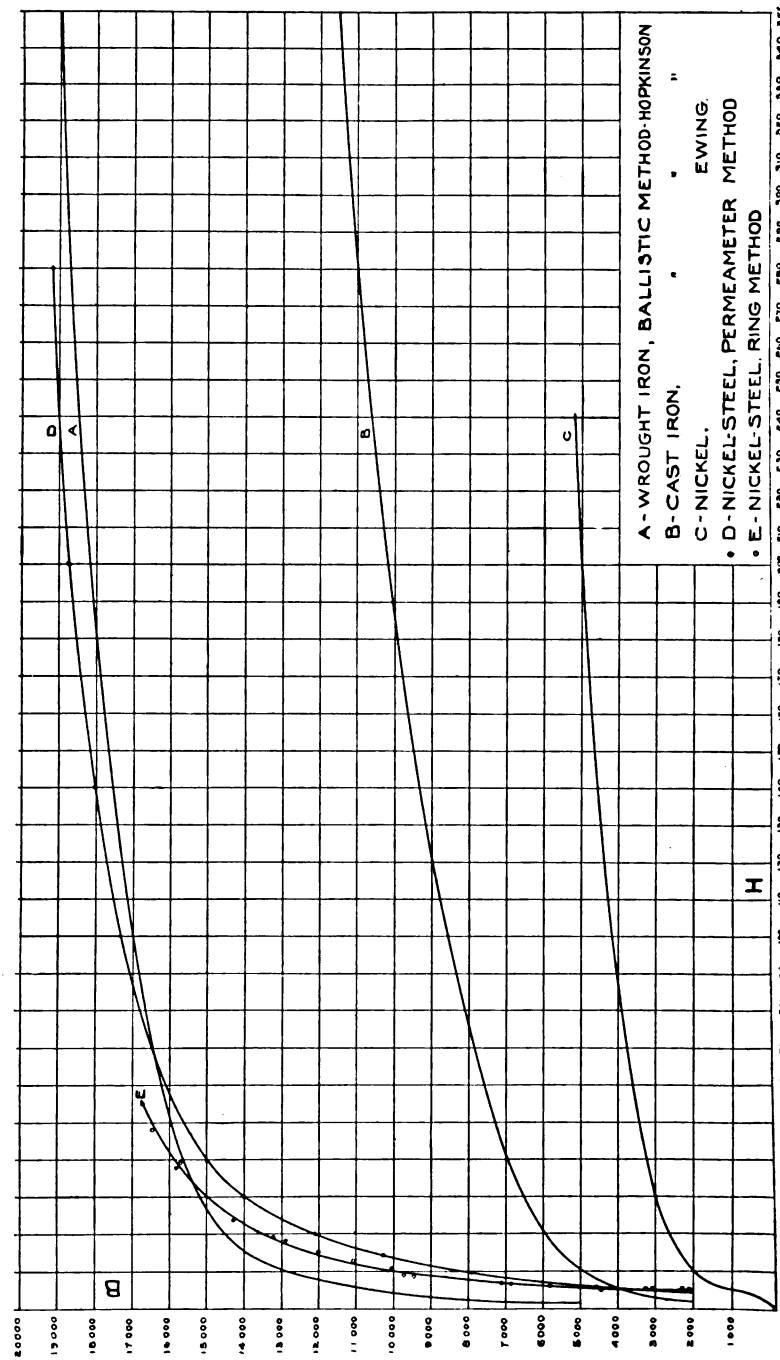

FIG. 4.

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they were insulated by sheets of mica with heavy strips along the edges where the coil would otherwise press most heavily against the box. The weight of each pole piece with its bobbin is 2800 lbs.

The bronze collector rings are built upon a separate cylindrical casting placed above the driver and securely fixed to the hub of the latter by heavy screws through a flange at its base. The brush-holder rods are held in place by a heavy iron bracket encircling the casting below the collector rings. This bracket rests upon the bridge which spans the machine and gives access to the collectors, brush-holders and brushes.

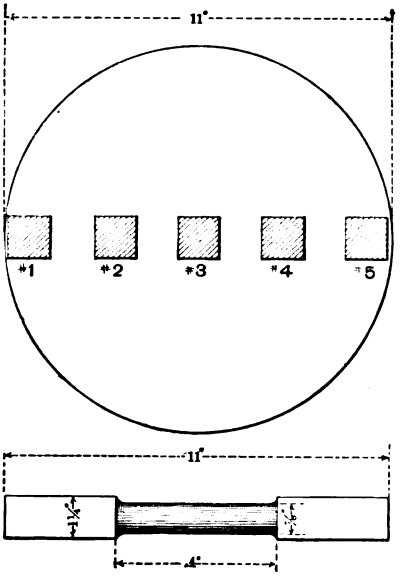

FIG. 5.

Driver.—The field ring is carried by an umbrella-shaped steel casting, to the periphery of which the ring is secured by bolts as shown in the vertical section Fig. 2. The driver is turned on its outside surface and is strengthened by six deep ribs on the inside. The steel used is of excellent quality, samples taken from a casting near the periphery of the first driver, which samples are fairly representative of all the drivers, showing by test a tensile strength of 74,000 lbs. per square inch, an elastic limit exceeding 44,000 lbs. per square inch, an elongation of 30% in three inches,

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and a reduction of area of 43%. The surfaces of the fracture where specimens were broken were silky and fine-grained.

Shaft.—The shaft is tapered at its upper end to receive the driver and at its lower end a forged flange 27″ in diameter provides means for connection to a similar flange at the top of the turbine shaft. These flanges are held together by eight tapered steel bolts. The diameter of the shaft in the bearings is 12 $\frac{15}{16}$ inches. It is tapered at the upper end to receive the driver and is also threaded to provide means for securing in place an iron casting which projects above the driver and carries the collector rings. A key-way is cut in the tapered end of the shaft and also in the bearing of the driver which is fitted to it, the driver and shaft being held together by a long, massive steel key. To obtain information with regard to the physical properties of the steel used for the shaft of the first three alternators, they were forged of extra length. An end several inches in length was then cut off and from these five samples were taken, two being cut from the periphery of the shaft at opposite ends of the diameter, one from the center of the shaft and two from points midway between the periphery and the center, as illustrated in Fig. 5, where the numbers 1, 2, 3, 4 and 5 indicate the places in the section of the shaft from which the test samples were taken. These samples were tested for tensile strength, elastic limit, reduction of area and elongation, and the results, as set forth in the following table, show in an interesting manner the fact that solid forged shafts are stronger near their outer surface than elsewhere.

Sample number.	Tensile strength in lbs. per sq. inch.	Elastic limit in lbs. per sq. inch.	Reduction of area in percentage area before test.	Elongation in percentage of length before test.
1	63,000	35,500	53	37·5
2	59,000	29,500	51	38
3	56,000	28,500	37·5	31
4	58,500	31,500	41·5	38
5	62,500	35,000	55·5	35

Bearings.—Babbitt lined bearings are used and provision is made for cooling the bearings by circulation of water through openings in the cast iron bearing boxes. It is interesting to note that the babbit lined bearings of the alternators have been satisfactory from the start while the bronze guide bearings originally provi-

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ded for the shafts connecting the first three turbines with the corresponding alternators gave much trouble and have all been replaced by babbitt lined bearings.

Method of Balancing the Revolving Field.—The method employed in balancing the revolving element of the alternators was devised by Mr. Albert Schmid and is illustrated by Fig. 6.

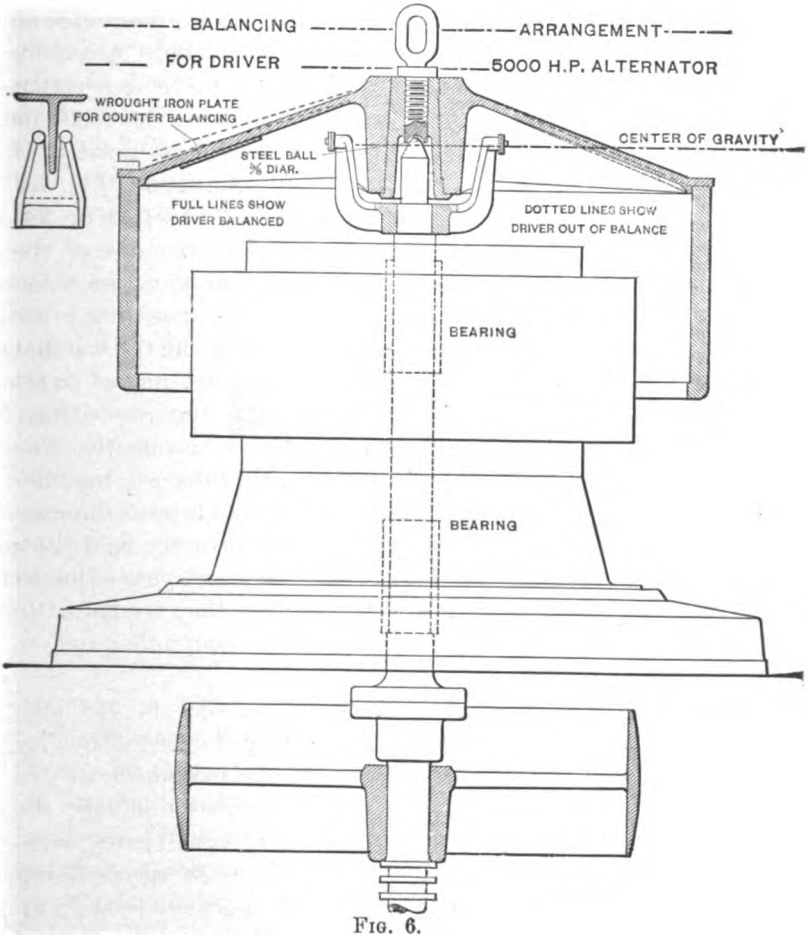

FIG. 6.

A special shaft is placed in the bearings of the machine, and supported at its lower end by a thrust bearing into which oil is pumped at a pressure of about 1,000 lbs. per sq. in. This pressure is sufficient to lift the weight of the revolving parts, and the collars on the shaft are separated from the grooves of the thrust

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bearing by a thin layer or film of oil. A small piece of tool steel is set into the upper end of the shaft, a half sphere or cup being cut in the upper surface of this tool steel, in which is placed a tempered steel ball $\frac{3}{8}''$ in diameter. A large eye-bolt with a similar piece of tool steel, having in its lower surface a cup bearing similar to that at the top of the shaft, is secured in the taper bearing of the umbrella-shaped driver, to the periphery of which the field ring is bolted. The entire weight of the driver and the ring is thus supported upon the small steel ball. A casting secured to the shaft serves to rotate the driver and ring with the shaft. The steel ball, as will be noted in the illustration, is placed a very short distance above the centre of gravity of the field and driver, and under these conditions, the driver and ring being free to rock while rotated, a defect in balance is quickly shown. As a matter of fact, in the case of the first alternator the driver at first assumed the approximate position indicated by the dotted lines. This was corrected by rivetting to the driver a wrought iron plate, the weight of this plate and the distance from the axis of rotation being experimentally determined to obtain not only exact static balance but also exact running balance.

The driver is first balanced in this manner independently. The ring is then bolted to the driver, and the two balanced together as shown in the illustration. It is not necessary to balance the combination of the driver, ring and field poles since the field poles and bobbins are separately weighed, and their weights adjusted to exact equality, while the positions in which they are bolted to the ring are symmetrical with reference to each other and to the axis of rotation.

Armature.—The sheet steel used for the core is .015 inch thick. Difficulty was experienced in securing the desired quality and it was found impracticable to obtain absolute uniformity in the large quantity required. To secure circulation of air, the armature core is divided horizontally into six equal parts, separated from one another by one inch spaces, these spaces being maintained by brass spacing strips, whose position is approximately radial to the machine. Each layer of the core consists of eleven segments which are so placed that all joints in each layer are overlapped by the segments of the adjacent layers. The plates are annealed, but in the first three alternators are not japanned.

The laminated ring thus built up to form the armature core is held together by 66 bolts of nickel steel containing a high per-

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centage of nickel which renders them practically non-magnetic. These bolts are carefully insulated from the core. The large disks or end-plates at the top and bottom of the armature ring are of brass. At the time of tightening the bolts, the steel plates were pressed closely together by powerful hand presses. The entire ring constituting the armature core when finally built up was turned on the inner surface so as to accurately fit the ribs of the armature support. It was then heated and lowered into place against the flange on the support and in cooling, of course, adjusted itself tightly into place against the ribs. The armature conductors are copper bars $1\frac{1}{2}'' \times \frac{7}{16}''$ in section, the edges of the bars being rounded to a radius of about $\frac{1}{8}''$. Two of these bars are placed in each of the 187 slots around the periphery of the armature core. The conductivity of the bars is above 100%

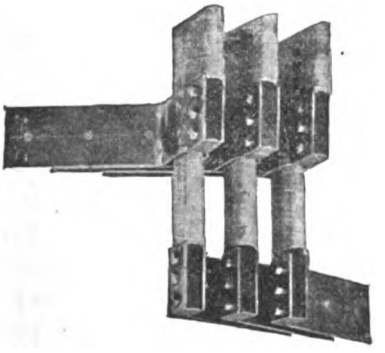

FIG. 7.

by Matthiesen's standard, the actual conductivity in the case of the second alternator being 102.6% by that standard. The bars are encased in mica applied before they are put in place. The insulation is about $\frac{3}{2}''$ thick. The insulation of each bar was tested by connecting one terminal of an alternating potential to the conductor, while the other was connected to a layer of tin-foil wrapped about the tested insulation. The insulation of every bar was required to withstand 15,000 volts, alternating, applied for a few seconds. The completed armatures were tested by the application of 8,000 volts, alternating, for a period of about one minute. The armature bars project above and below the core and connections are made by pieces of copper punched from

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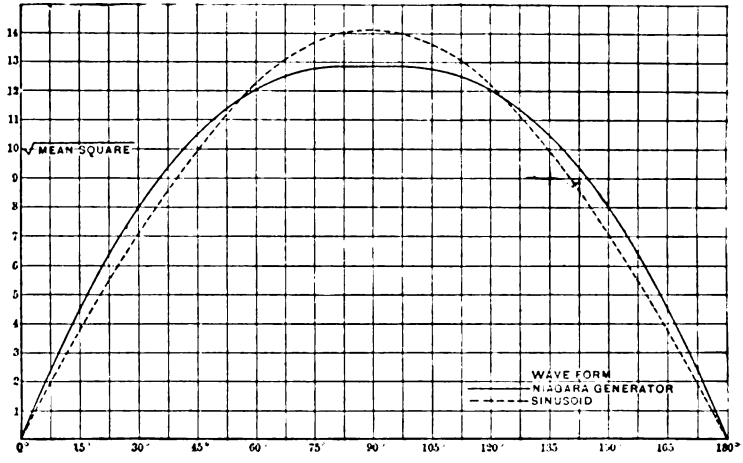
large sheets and shaped into proper form by presses and iron molds. These connections are insulated by mica and rubber insulating tape, the former being used only when connectors conveying considerable difference of potential are adjacent to each other. The connectors are secured to the armature bars by three wrought iron bolts the heads of which are countersunk in one side of the split connector, while the nuts are locked by upsetting the projecting ends of the bolts. Finally, the joints are thoroughly soldered. Fig. 7 shows the junction of six armature bars and connectors before they are soldered and insulated. The conductors are so connected as to form two complete circuits, each thoroughly insulated from the other and from the steel core.



THE POTENTIAL CURVE FOR ONE OF THE GENERATORS.

FIG. 8.

Potential Curve During a Half Cycle.—The potential curve of one of the first three alternators during a half cycle, and for purposes of comparison a sine curve, are shown in Fig. 8. The following interesting method was adopted in determining the form of this curve :

The machine was run at a very low speed so that the needle of an ordinary voltmeter connected across the terminals would follow the variations of electro-motive force, increasing to a maximum, decreasing to zero, reversing and increasing to a maximum in the reverse direction. Readings upon the voltmeter were made at regular intervals and the results plotted, thus giving the curve of the machine.

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This method of measurement requires a uniform and very slow speed. Variations of one or two per cent in the speed will cause corresponding variations in the electro-motive force. In the test the slow speed was obtained by winding around the field ring a wire rope, which was attached to the shaft of a vertical lathe. The lathe was run at a slow and uniform speed, winding up the rope, which was drawn from the ring, thus revolving the machine. Difficulty was experienced at first in obtaining a uniform speed when heavy iron wire was used instead of the cable finally adopted. The speed was irregular, due to stretching of the wire, as the friction to be overcome was not uniform at the slow speed. The adoption of a steel cable very nearly eliminated the irregular motion. The machine was belted to a direct current motor supplied with current nearly sufficient to cause rotation, and the additional force was supplied by the cable which was able in this way to maintain a uniform speed.

The speed of the ring was about one revolution in ten minutes, giving one alternation in about 50 seconds. The speed of the machine is thus reduced from normal, 250 revolutions, to one-tenth revolution per minute, or in the ratio of 2500 to 1, and the electromotive force of the normal field charge is consequently reduced from 2000 volts to .8 of a volt effective, or a little over one volt maximum. This electromotive force could be reduced as desired by resistance in circuit with the voltmeter. In making the measurements, a voltmeter was placed across each of the circuits and readings were taken at intervals of $2\frac{1}{2}$ seconds, as indicated by a signal. Observations were continued through several minutes, covering a number of cycles. The results were plotted and the successive cycles which should be similar, if all the conditions remained constant and the observations were correctly taken, were superposed and the average adopted as the correct result. Variations in speed and in the time of taking readings, and in the readings themselves, were in this way found to be slight and were eliminated by taking averages. The voltmeter was a Weston milli-voltmeter with the zero of the scale in the middle so that both positive and negative readings could be taken without changing connections.

The wave form of the machine was also calculated directly from the drawings. The calculated and measured curves agreed very closely.

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V. The First Three Alternators Under Test and in Service.

The manufacturer guaranteed that the total electric and magnetic losses, when delivering 3730 killowatts, should not exceed 2½% of the power required to drive the alternator. Before shipment, therefore, tests were made in the shops at Pittsburg to determine the losses due to magnetization of the armature core, the alternator being supported on a thrust bearing into which oil was pumped at a pressure of 1000 lbs. per square inch to support the weight of the revolving field which was driven by a direct current motor. The fields of the motor were separately excited. The energy delivered to the motor was measured by Weston ammeters and voltmeters previously compared with standards, and simultaneous observations of speed, field charge, potential at terminals of alternator and current delivered to the motor were recorded. These tests were repeated a number of times and satisfactory agreement of results was obtained. The energy required to magnetize the field was accurately measured in the course of full load tests carried out in the power-house where a large rheostat was constructed and used for loading the alternator. The loss due to resistance of the armature conductors was calculated from the measured resistance and the known mean current. No allowance was made for possible eddy currents in armature conductors. The losses and efficiency in the case of the first three alternators thus determined were as follows:

Loss in armature core	42 K.W.
I^2R loss in armature	29.2 K.W.
I^2R loss in field	11.4 "
Total	82.6 "
Kilowatt output	3730 "
Kilowatt input	3813 "
Efficiency	97.82 %

Ventilation.—Much difficulty was encountered in securing proper circulation of air throughout the interior of the machine. When the alternators were designed it was expected that a plenum would be established in the interior of the armature, and that the air would flow radially outward through the armature core. Six holes in the driver were provided for ventilation, and above each of these holes a copper ventilating-hood, opening forward—*i. e.*, in the direction of rotation—was placed.

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The space within the armature support is open at the top, no hatches being used between the five radial arms at the top of the bearing support, and as it was at that time deemed inadvisable to reduce the strength of the ring by providing openings through it for radical escape of the air, some difficulty was experienced in establishing satisfactory ventilation. After some experimenting, the position of the hoods on the top of the driver was reversed, with the idea that they would thus act as exhaust or suction blowers to draw the air out of the interior of the machine, and after this change was made, excellent ventilation, except at the top of the armature, was secured, the air being drawn in through the space between the field and armature and the space between field poles, flowing thence inward radially through the armature core and finally escaping through the openings in the driver, the total amount of air thus passing through the machine being not less than 9,000 cu. ft. per minute. At the top of the armature, the cast-iron armature support, being designed for an expected plenum inside, interfered to some extent with the flow of air through the upper ventilating space in the core, as a consequence of which the temperature as measured at the top of the core exceeded the guaranteed limit, viz., 50° C. above surrounding air, by about 10° C. Water cooling devices in the shape of shallow copper boxes applied to the inner surface of the cast iron armature support were added to the first three alternators but in practice they are seldom used as experience has shown that the temperature attained by the machines does not seriously endanger and apparently does not practically injure the insulation used.

Original Field Coils Defective.—As I have stated, the conductors used in winding the field coils originally designed for the first three alternators were covered with cotton insulation. Under test, the temperature of these coils, as determined by thermometer applied to the outside of the shells and as determined by measurement of resistance, was well within the guaranteed limit—*i.e.*, 50° C. above surrounding air; but after the machines had been operated for a time it was found that the exciting current was gradually increasing from week to week and from month to month. Investigation showed that this was caused by excessive heat in the middle of the coils, which was gradually charring the cotton insulation and causing a part of the current to leak across from one layer to another, instead of following the conductor.

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The coils which had proved defective were replaced by coils of a new type, in which the conductor is a copper strap $1\frac{3}{16}'' \times \frac{1}{16}''$ in section, bent on edge, successive turns being insulated by micanite placed between them as in commutator construction. The edges of the strap conductor are exposed to the air. This type of construction is now extensively used, but I think was first used in these alternators. There are four layers of turns separated from each other by insulated spacing-rods, the whole being enclosed in a metallic case provided with abundant openings for circulation of air. These coils in service under full load rise only 12° C. above surrounding air, as determined by thermometer and by measurement of resistance.

The first alternator was put into commercial service October, 1895, the second alternator following a few months later, and the third beginning its commercial work in 1897. They have been in practically continuous use ever since they were started, being shut down regularly once a week for a few hours, when they are thoroughly cleaned and inspected. Allowing for all stoppages, the use of the first three alternators to date in actual running time is more than equivalent to five years' absolutely continuous use, and in that time there has been no failure in any part of any one of the three alternators which has caused one minute's interruption of service. This excellent record is undoubtedly due in part to the system of inspection and testing adopted, each alternator being thoroughly cleaned once a week, while at intervals of about three months the armatures are subjected to a test potential of 6,000 volts, and any armature bars having insulation which will not withstand this test are removed and replaced by others. This, in my opinion, is the proper manner to take care of electrical machinery. The total cost of maintenance of these alternators since the field coils were replaced has not exceeded 1%, whereas if they were not kept in first-class condition it is not difficult to imagine how accidents might occur, causing much and expensive damage.

VI. Alternators 4 to 10.

Alternators 4–10, inclusive, were designed in 1896. The first alternators had been erected, tested and were in commercial service. As compared with the first three alternators, which were designed in 1893, the following differences were introduced:

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The thickness of the field rings was increased from $4\frac{7}{16}$ inches to 5 inches. A slight reduction in weight of the shaft connecting turbines and alternator made it possible to increase the weight of the revolving field by about 2,000 lbs. The additional weight was put into the ring as being most effective there, both with respect to strength and flywheel effect. The increased thickness made it possible so to do without reducing the factor of safety in the ring below the standard established for the first three alternators. The heads of the bolts which hold the field poles to the ring were countersunk.

Tests of additional samples of nickel steel having demonstrated that an alloy containing 4½% nickel would be satisfactory with respect to permeability and ductility, while superior with respect to ultimate tensile strength and elastic limit, steel containing 4½% nickel was used for the rings of the alternators 4–10.

The following table shows results of tests of samples from number of these rings. It is safe to say that no better steel has ever been used in the construction of dynamos.

	Tensile strength lbs. per sq. inch.	Elastic limit lbs. per sq. inch.	Elongation in 2" about	Reduction of area.
Specified requirements.....	90,000	45,000	18%	
Obtained in samples representing various rings.	93,150	55,890	23.75	47.82
	95,510	58,530	18.65	39.29
	98,290	63,150	19.60	42.84
	90,140	51,590	24.30	49.01
	94,600	57,270	23.80	46.18
	92,040	52,150	20.10	35.41
	90,650	50,930	20.50	34.70
	95,740	57,040	23.60	44.64
	96,250	58,060	23.65	45.53
	95,740	55,000	25.65	46.70
	104,030	61,800	20.75	——
	99,200	56,250	22.15	——
	103 290	60,330	20.25	——
	93,710	65,180	21.00	41.31
	93,200	66,720	21.50	41.92

The permeability of samples from these rings was very close to that of the rings which contained about 3¼ per cent. nickel as illustrated in Fig. 5.

The winding of the armature was modified with a view to securing an increase in efficiency and closer regulation, the new winding consisting of 334 bars placed in an equal number of slots in place of 374 bars placed in 187 slots.

The clearance between armature and field was reduced from 1 inch to 7/8 inch.

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For the old method of building up the armature core, which involved the use of nickel steel bolts, the now generally adopted method of dove-tailing the sheet steel plates of the armature into grooves on the outer periphery of the cast-iron support and holding the complete core in place by end plates, secured by means of circular keys, was adopted. This improvement in the method of manufacture in connection with the more uniform quality of steel obtainable, the painting of the plates by an insulating varnish and the more accurate punching and fitting of the plates, which made it unnecessary to do as much filing of the slots as was required in the case of the first three alternators, resulted in a reduction of the core loss amounting to about 15 kilowatts. Instead of six horizontal one inch ventilating spaces through the armature core, twelve spaces of about $\frac{1}{2}$ inch were provided and the openings through the cast iron armature support were extended in such a way as to permit more effective ventilation in the upper part of the core.

As regards shaft and bearings, hollow forged nickel steel shafts were substituted for the solid shafts used in the first three alternators and the iron shell surrounding the babbit-lined bronze bearings was cored out to permit circulation of water and was not split, this improvement making it absolutely impossible for the oil and water used in cooling and lubricating the bearings to get mixed to the detriment of the oil.

During the period which had elapsed since the first alternators were designed, the manufacture of hollow forged shafting had been brought to a high degree of perfection by the Bethlehem Iron Company and in line with the policy of the Cataract Construction Company, which aimed to secure nothing less than the best in material and design, they were adopted for the new alternators. The use of the hollow forged shaft had reference also to the use of a very ingenious torsion dynamometer designed by Dr. Coleman Sellers and intended to measure the force delivered to the alternator by the turbine shaft. The use of the hollow forged shaft made it possible to dispense with the bridge over the alternator by placing the collector rings below the armature and carrying the exciting current to the field through conductors placed inside the shaft. This arrangement was not adopted for alternators 4–10, however, as the change in external appearance caused by removing the bridges would be radical and it was thought desirable to maintain in all alternators installed in the same power-house general uniformity of design.

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The reduction in losses, particularly in core loss, implied of course a reduction in heat to be dissipated, and as by reason of increased thickness the rings were stronger than those used for the first three alternators, it was thought safe to provide openings for ventilation along the upper edge of the ring where it is secured by bolts to the driver. It was decided, therefore, to omit the ventilating hoods from the new alternators, but as this omission involved some uncertainty as to the ability of the machine to operate within the desired temperature limit, provision was made for cooling the interior of the machine by water circulating through the cast-iron armature support. When the machines were completed and tested, however, it was found that they would operate within the required temperature limit without the use of water.

VII. Performance of Alternators 4–10 Under Test and in Service.

Efficiency.—The method adopted for determining the efficiency of alternators 4–10 was the same as for the first three alternators, *i. e.*, the core loss was determined by measuring the increase of power required to drive the alternator with charged field as compared with the power required to drive it at the same speed with no field charge; the $I^2 R$ loss in armature was calculated from the mean current and the measured resistance; and the $I^2 R$ loss in field was also calculated from measured current and resistance. To the core loss at no load, 20% was added to cover increase due to distortion of magnetic field in the armature under full load and for partial loads the measured core loss at no load was increased proportionately. The following tabulated statement of electric efficiencies of alternators 4, 5, 6, 7 and 8, is an exhibit which should be gratifying to the manufacturer, to the purchaser and to the members of the Institute, as showing what electrical engineering science in America was able to accomplish in 1896, within twelve years of the time when alternating current electrical machinery first appeared within the horizon of practical application.

Total amps. at 2400 volts.	Elec. Eff. Alt. No. 4.	Elec. Eff. Alt. No. 5.	Elec. Eff. Alt. No 6.	Elec. Eff. Alt. No 7.	Elec. Eff. Alt. No. 8.
400 amps.	96.20 per cent.	95 99 per cent.	96.85 per cent.	96.4 per cent.	96.2 per cent.
800 "	97.65 "	97.6 "	98.1 "	97.78 "	97 66 "
1200 "	98.00 "	97 96 "	98.25 "	98.11 "	98.02 "
1600 "	98.1 "	98.07 "	98.32 "	98.18 "	98 10 "
2000 "	98.12 "	98.06 "	98.33 "	98.15 "	98.07 "

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The first three alternators designed in 1893 and 1894 were to all intents and purposes as effective as the fourth and succeeding alternators, except that methods of manufacture were not then sufficiently perfected as regards treatment and handling of armature cores to permit reduction of the core losses within the limit established by the succeeding alternators, the result being that the efficiency of the first three alternators was about .3 of one per cent. lower than the efficiency of the others as shown in the table; in other words, the electrical full load efficiency of the first three alternators was about 97.8% while the electrical efficiency of the last seven alternators averages fully 98.1%. The mechanical friction, *i. e.*, air friction and bearing friction, amounts to 1.1%. The net commercial efficiency of the first three alternators is, therefore, 96.7%, and that of the last seven alternators, 97%. Surely, results such as these, considered in connection with the excellent record of these machines in practical operation, leave no ground for belief that the designers of 5,000 H. P. alternators are in any way less certain to attain desired results than the designers of large engines, or turbines or bridges.

Temperature.—In determining the temperature, thermometers were applied to the outside surfaces of the armature, as was done in testing the first three alternators, and in addition to this the much more delicate and accurate method of determining rise of temperature by increase in resistance of exploring coils placed in the ventilating slots of the armature core was adopted. The exploring coils were made of wire .0025 inch in diameter, which was furnished by a dealer as platinum wire. Our determination of the coefficient of resistance in rise of temperature, however, showed that the wire was not pure platinum. The coefficient of these exploring coils was determined by measurements of resistance at various temperatures ranging from 10° C to 85° C., while coils were immersed in an oil bath. A series of measurements was made beginning at 85° C. and reducing the temperature to 10° C., from which point the temperature was again gradually raised to 85° C. During these measurements, the oil was stirred and the results obtained were gratifying, the maximum variation in the coefficient, as determined by a number of successive measurements, being less than 1%.

The coefficients being thus determined, the lengths of the coils were so adjusted that an increase of .1 of an ohm in the resistance

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of a coil corresponded to a change of 1° C. in temperature. In determining the rise of temperature of the armature core, one of the exploring coils was located in the ventilating slot nearest the top of the armature, one in a slot about half way between top and bottom, and one in the slot nearest the bottom of the armature. The exploring coils were wound on a thin piece of mica about one inch in width and three of these coils were placed about two inches apart and secured to a piece of fibre one inch in width and 10 inches long. The coils were secured in place by a tape and the piece of fibre with the taped coils was inserted radially in the ventilating slots. Between the resistance coils and the iron of the armature core but one layer of linen tape intervened, and the coils were thus brought into intimate contact with the iron and the armature.

The purpose of this arrangement was to observe the differences in the temperature of the armature core at several points along a radius, one of these points being located within an inch of the inner edges of the armature conductors, another being two inches nearer the vertical axis of the alternator, and a third four inches nearer the vertical axis of the alternator.

During the early part of each test, *i. e.*, while the increase of temperature was comparatively rapid, the resistance of the exploring coils was measured every 15 minutes by means of an Elliott Bros. bridge in connection with a D'Arsonval mirror galvanometer. The sensitiveness of the galvanometer was such that the difference in the resistance of a coil due to the maximum rise of temperature produced an equivalent throw of nearly 5,000 feet in the ray of light on the scale and a movement of $\frac{1}{25}$ of an inch could be easily read. As the temperature, and therefore the resistance of the coil, increased, the ray of light could be seen to move along the scale at a rate approximating 25 feet per minute. The measurements obtained were very satisfactory, the exploring coils nearest the armature conductors showing temperatures a few degrees higher than temperatures measured by thermometers applied to the outer periphery of the armature core. They also indicated that even the exploring coils nearest the armature conductors did not measure the temperature of the hottest parts of the armature. This will be apparent upon examination of Fig. 12, showing graphically the rise of temperature as determined by an exploring coil placed in the slot nearest the top of the

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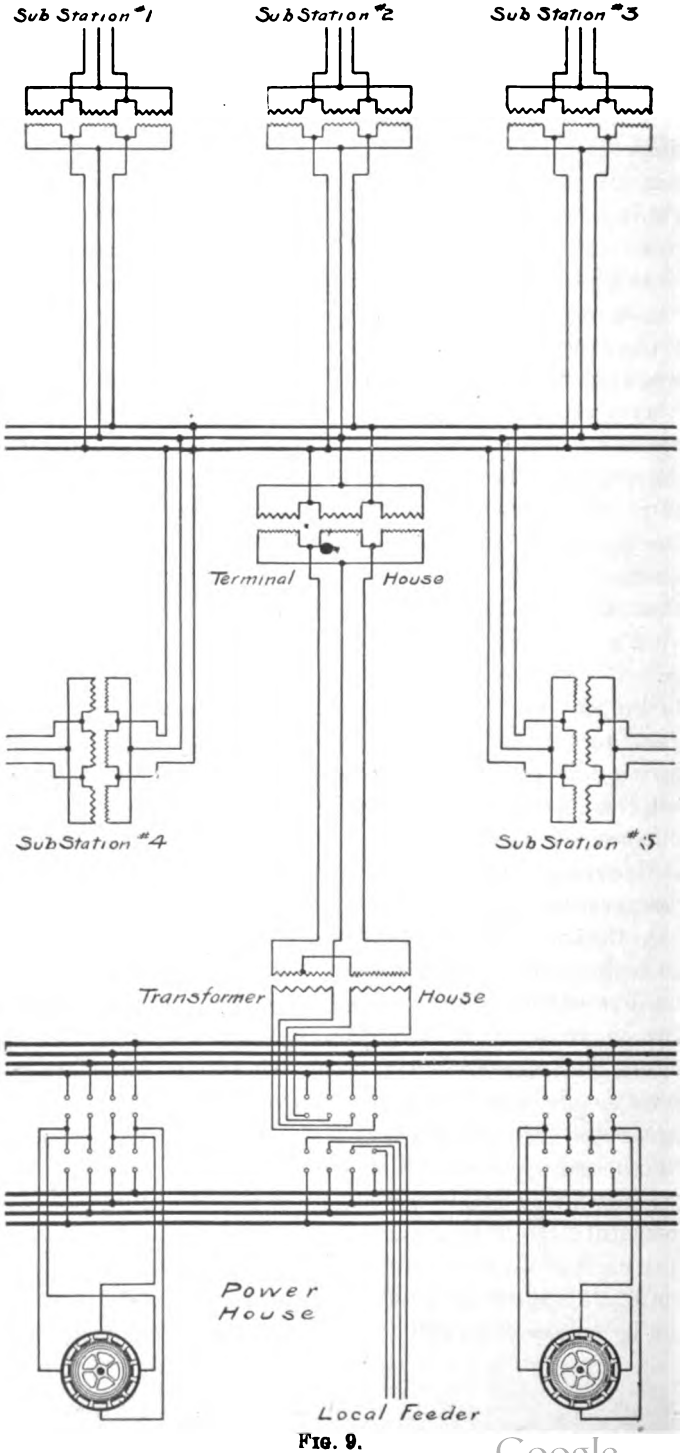

FIG. 9.

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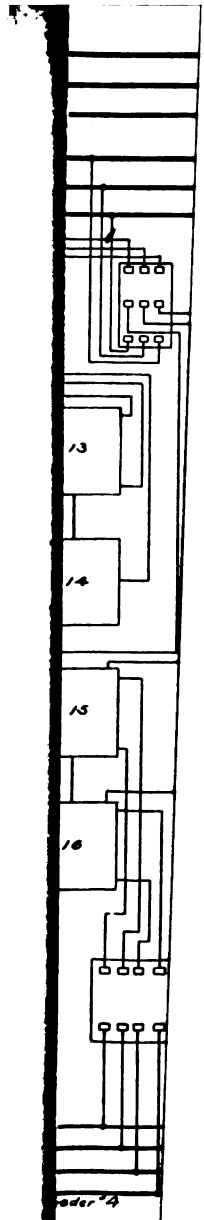

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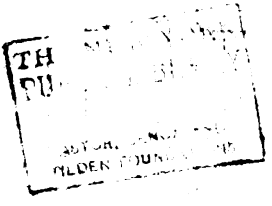

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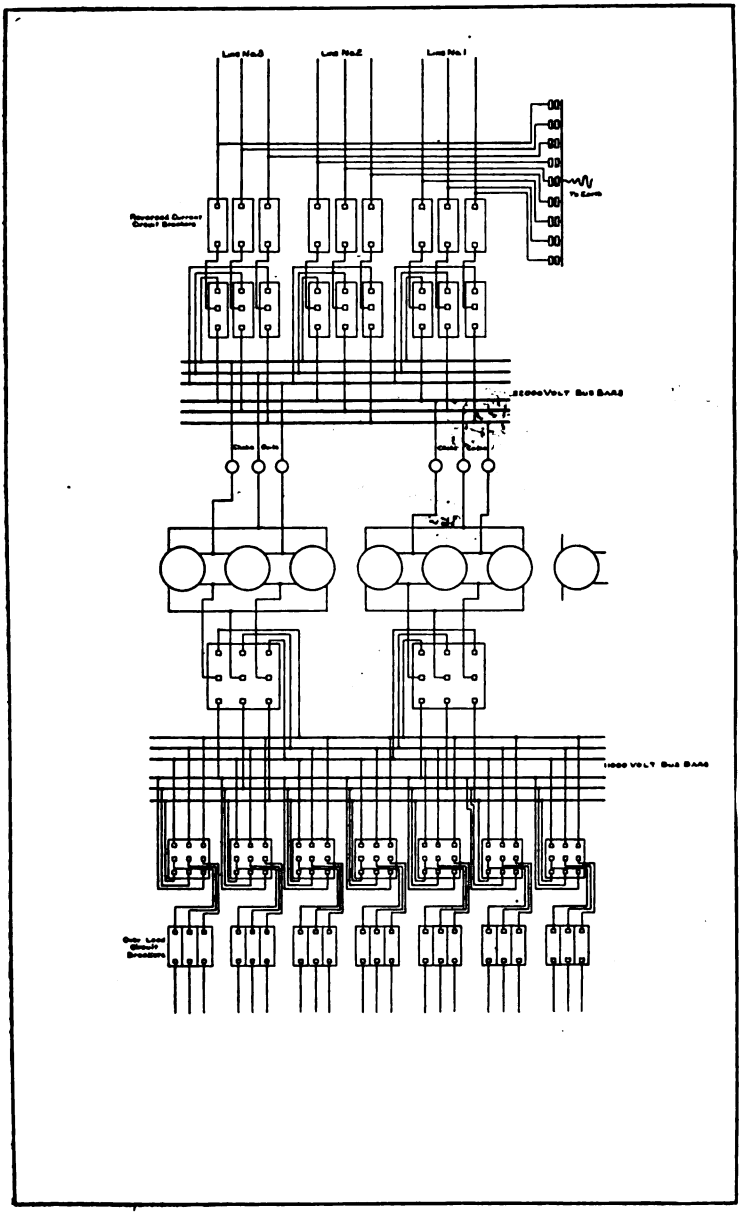

FIG. 11.

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alternator. The solid lines show temperature of coil and temperature of external air when water circulation is used. The dotted lines show temperature of coil and temperature of external air when the armature is cooled by ventilation only, water circulation through the armature core being stopped. It will be noted that after the machine has apparently attained its maximum temperature at the end of a run of about 4½ hours, there is a sudden rise of about

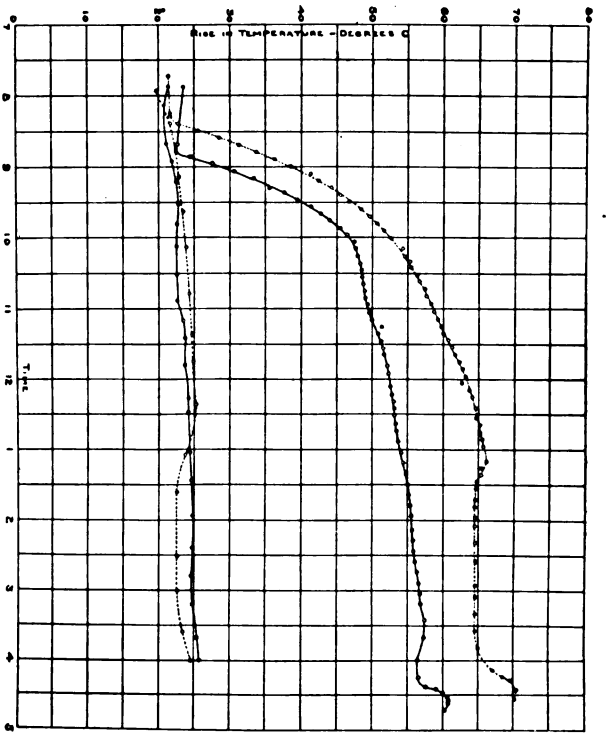

FIG. 12.

5° C. This occurred when the machine was stopped, as a consequence of which the powerful draft of air through the ventilating spaces of the armature core ceased. The sudden rise may be explained by saying that after the machine is stopped, the temperature, which is a maximum in the teeth immediately adjacent to the conductors, tends to equalize itself and a thermal wave spreads inward radially, increasing the temperature of those parts immediately adjacent to the exploring coils.

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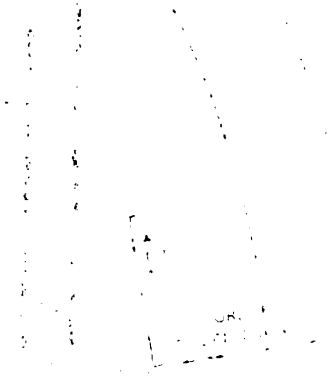

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Insulation Resistance.—Measurement of resistance of insulation by a Wheatstone bridge is of very little practical value as it varies between wide limits, depending upon the temperature of the machine, and the humidity of the air. The only important and conclusive test of insulation resistance of armature and field winding is a test of the dielectric strength by subjecting the insulation to a potential considerably in excess of that which it is designed to withstand in service. It is better of course to use a relatively very high potential for a short time rather than a moderately high potential for a longer time to avoid injuring the insulation. In the factory, the insulation of each bar of the armature winding of the fourth and succeeding alternators was tested by applying 15,000 volts, alternating, for a period of one minute. The insulation of the completed armature as erected in the power-house was tested by applying 6,000 volts, alternating, for a period of 10 minutes between the conductors and the iron core. Insulation of the field winding was tested by applying 2,000 volts, alternating, for a period of 10 minutes. In all of these tests, the form of the potential wave during a half cycle was approximately a sinusoid.

Damage to Armature Winding Caused by Short-Circuits.—With respect to ability of the armature winding to withstand the strains of magnetic attraction and repulsion caused by short-circuits, the winding of the new alternators proved less satisfactory than that of the first three machines. The magnetic force exerted momentarily by the enormous currents flowing through the armatures and external circuits when a failure of cable insulation resulted in a short-circuit can be realized from the statement that insulated conductors of 1,000,000 c. m. section, weighing upwards of 3 lbs. per linear foot, have been thrown off from their supporting brackets to a distance of 5′ or 6′, and in at least one instance a cable of this kind was thrown from the brackets on one side of the bridge between the power-house and the transformer-house with such force that a considerable length of it was caught by the projecting cable supports on the opposite side of the bridge and did not fall to the floor. In this instance the cable was thrown a horizontal distance of approximately 5′ while falling not more than 2½′. The strain upon the connectors and armature bars of these alternators where they project above and below the core is very great under conditions of short-circuit such as these, and in a number of instances the armature bars of the new alternators

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have been sufficiently bent to damage the insulation. This difficulty has been apparently overcome by inserting wooden spacing-strips between the projecting ends of the armature bars. The point is one of importance, and should not be overlooked in the design of large dynamos. The trouble is caused apparently by the excessive stray magnetic field when the machine is short-circuited. The stray field is less in the later machines than in the first three alternators, but the armature bars are but half as thick—$\frac{7}{32}''$ as compared with $\frac{7}{16}''$—and a greater tangential movement is therefore possible.

Changes Introduced in the Construction of Alternators 4–10 Not Material as Affecting Their Money-Earning Power.—I would ask you to carefully note that the changes introduced in the design and construction of the alternators 4–10 as compared with the first three alternators in no sense materially affect the commercial usefulness of the machines. Considering the machines with reference to their money-earning power, there is little to choose between the first three alternators and their successors. The advantages of the latter may be summed up in the statement that their efficiency is about .3 of 1% higher, that their regulation is somewhat closer, and that their limiting temperature under continuous full load is about 15° C. lower.

The armature insulation of none of the first three alternators has broken down in commercial service, and examination of the insulation of bars which have been in use since 1895 shows no apparent deterioration. It would seem safe to conclude, therefore, that a temperature rise of 60° C. above surrounding air, or absolute temperatures in continuous service ranging from 85° C. to 100° C., acts very slowly, if at all, in causing deterioration of the micanite insulation used in this case. The improvements embodied in alternators 4–10, in so far as they are practically material, are the result of improved methods of manufacture rather than improvements in design.

VIII. The Exciters.

During the period of construction, current for exciting the fields of the alternators was obtained from a 75 K. W. continuous current engine driven generator and from 200 K. W. rotary converters, two of which were installed for this purpose. These converters were of course supplied through step-down transformers and in the winding of these transformers provision was

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made for adjustment of the ratio of transformation, and consequently for adjustment of the potential of the continuous current delivered. A rheostat in the field of each alternator affords means for the necessary adjustment of potential.

When the wheel-pit was extended to permit installation of the fourth and succeeding units, provision was made for turbine-driven exciters, of which four are now in use. These exciters, are of 125 K. W. output; their speed is 550 R. P. M. One of them is capable of exciting the entire battery of ten alternators, but it is usual to keep two in operation for this purpose.

Excitation by separately driven exciters is preferable to excitation from rotary converters, since in the latter case variations of potential at alternator terminals are increased by reason of the fact that the potential of the exciting current delivered to the fields varies in sympathy with the changes due to variations in the external load. An increase in load, therefore, reduces the potential delivered to the A. C. circuits not only by reason of drop due to resistance and reaction of armature, but also by reason of a practically simultaneous reduction in strength of field. This of course was understood when the converters were put in, and they were installed only as a temporary expedient, pending installation of turbine driven exciters which could only become possible when the wheel pit was extended.

IX. Switching Apparatus and Measuring Instruments.

The design and construction of adequate switching apparatus, properly organized not only with reference to the three alternators originally ordered by the Cataract Construction Company, but also to future extensions of the Niagara development, was not the least difficult of the problems presented by the conditions to be met.

In 1893, no switch adapted to 5,000 horse-power circuits had been constructed and, so far as I am aware, no switch fitted to meet the conditions, both of large current—1,000 amperes per pole—and comparatively high potential—2,200 volts, alternating—had been attempted.

As to the general organization of apparatus, it was necessary to provide not only for the three initial alternators, but also for the operation of additional machines, of which it was expected that as many as 15 or 20 might be located in power-house No. 1, while others, to a possible ultimate number of 40 on the Ameri-

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can side of the river and 50 on the Canadian side of the river, might be installed. It was obviously essential also that the switching arrangements must be such as to permit operation of any or all alternators in parallel.

To meet the conditions, it was decided to so organize the switching apparatus as to provide for operation of the alternators in successive groups of five, the alternators of each group being connected to switching apparatus centrally located with reference to the group, with provisions for cross-connecting the bus-bars of different groups so that, if necessary, alternators of different groups might be operated in parallel with each other.

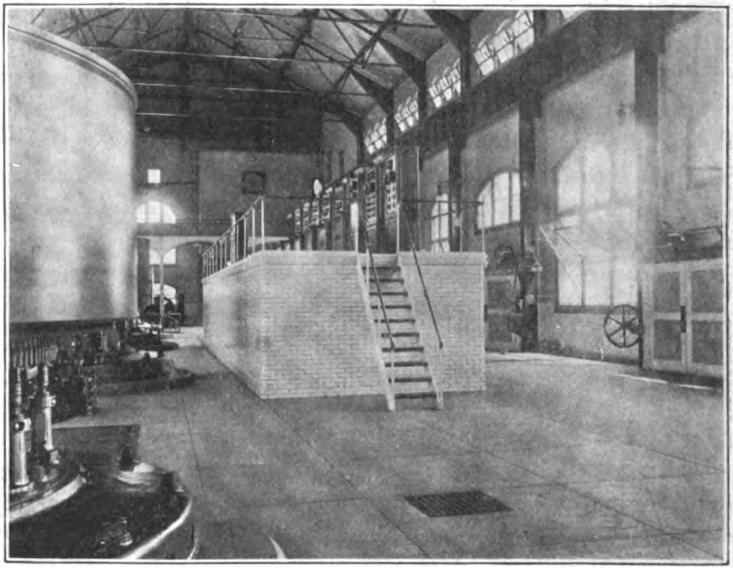

FIG. 14.

In previous organizations of switching apparatus, at least in America, the switches, bus-bars and measuring intruments had been assembled upon vertical panels of marble or slate, these panels being supported by a suitable frame work and collectively constituting what is called a "board." This form of construction is an inheritance from the earliest days of the commercial dynamo, when it was natural to place the switch and the ammeter and voltmeter at first upon a wall of the dynamo room, and later—when the advantages of running wires behind the

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"board" and the necessity of going behind it to look after connections, etc., had become apparent—upon a vertical switch-board independently supported and separated from the wall of the room by a suitable space.

The dimensions of a switch adapted to a 5,000 H. P. two-phase 2,200-volt alternator, as fixed by size of contacts necessary to carry the current and by distance between terminals required by the comparatively high potential, were such that operation by hand was considered impracticable and it was decided to employ pneumatic pressure to throw the switches. This made it possible

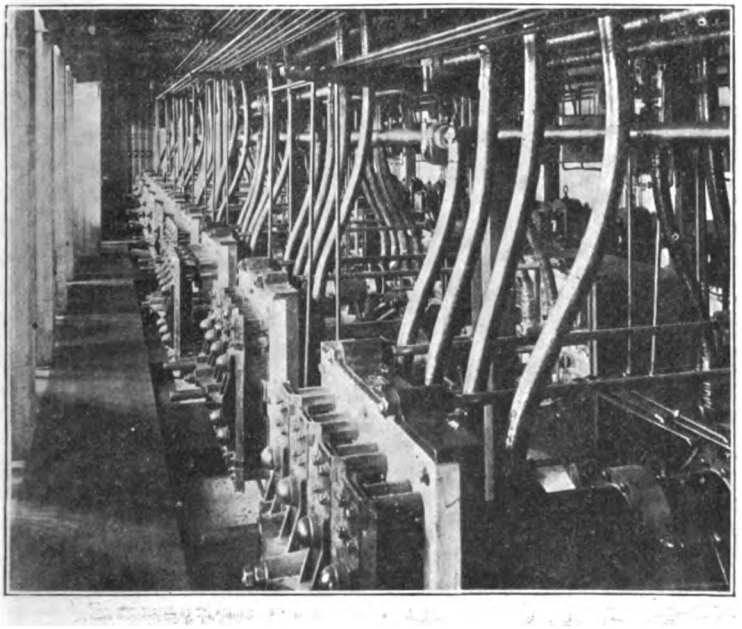

FIG. 15.

to locate the switches at a distance from the operator, who would thus be removed from danger in case of a short-circuit in the switches or a dangerous arc. Danger to the operator from accidental contact with charged terminals would also be eliminated in this way.

These being the general considerations in mind, the switching apparatus for the first group of five alternators was assembled in a switch room, or structure, erected over the cable subway which extends the entire length of the power house on a line parallel

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with the row of alternators. The position of this structure, and of a second one subsequently erected for the second group of five alternators, with reference to the alternators, is shown in Fig. 13 and exterior and interior views are shown in Figs. 14 and 15. The 5,000 H. P. switch itself is illustrated in Fig. 16.

The four leads from each alternator are connected to the bottom terminals at opposite ends of a switch; the upper terminals are connected by short pieces of insulated cable to the bus-bars which are supported in a horizontal position above the switches. Two sets of bus-bars are provided and any alternator may be connected to either set. Connections for the feeder switches are

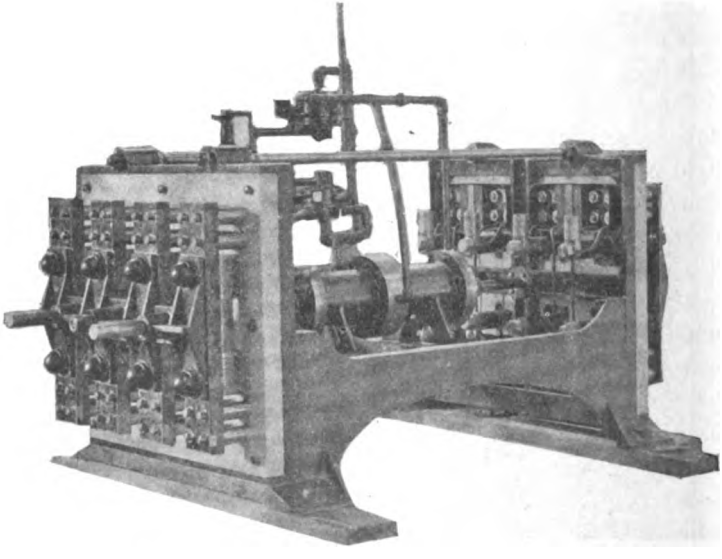

FIG. 16.

similar to those for the alternator switches except that bus-bars are connected to the upper terminals and the outgoing cables to the lower terminals at each end of the switch The bus bars are insulated by vulcanized rubber covered with braid and wrapped with twine. After erection, they were subjected to a puncture test of 10,000 volts alternating. The bus-bars taper from the middle toward each end, the section at all points being proportioned to the maximum current which may traverse the bars. They are circular in form, the end sections being copper rods $1\frac{1}{8}''$ in diameter and the intermediate sections copper tubes, the largest being

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about 3½″ in diameter. The rods constituting the end sections are threaded and screwed into the ends of the adjacent tubes, which in turn are threaded and screwed into the ends of the large tube constituting the middle section of the bar. The fitting and insulating of these bars was a work requiring much care and skill; it was admirably carried out by Dr. W. M. Habirshaw, Manager of the India Rubber & Gutta Percha Insulating Company, Yonkers, N. Y., which firm also supplied all cables for dynamo leads and connections.

The switches are supported upon I beams which span the cable subway. While I do not regard these switches as absolutely reliable in opening circuits conveying several thousand horse power, they have failed in service not more than two or three times since the plant was started and on the whole have done their work in a very satisfactory manner.

The ammeters and voltmeters, indicating wattmeters and synchroscopes, are mounted not upon a board, but upon individual instrument stands, one stand being provided for each alternator. These stands are located upon the platform which constitutes the roof or ceiling of the switch room. In front of each alternator instrument stand is a smaller one carrying the levers by means of which air is admitted to the switch cylinders. For each feeder circuit, lever stands equipped with pilot lamps and drop indicators are located upon the upper platform of the switch structure within convenient reach of the operator. The drop indicators were not included in the original outfit, but were added at a later date after the feeder fuses were dispensed with. In case of short-circuit, they indicate to the operator which of the several feeder circuits is in trouble. They are constructed very like the drop indicators in a telephone switchboard.

For each phase of each feeder circuit, an indicating wattmeter and a watt-hour meter are provided. These instruments are not placed upon the switch structure, but are located in the Superintendent's office, my theory being, at the time this installation was made, that the switch operator need see only the alternator instruments, while the division of load among the several feeders supplying different tenants of the company was a matter concerning the Superintendent. Incidentally, also, this arrangement by removing from the switching structure a large proportion of the measuring instruments, simplifies the organization of ap-

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paratus at that place, and improves the appearance of the platform of the switching structure which would otherwise be awkwardly crowded by instrument stands. An argument in favor of instrument stands as against an instrument "board," which considerably influenced the decision in favor of the former, was the fact that as instrument boards were then constructed it was not easy to put up a board for three alternators arranged for extensions to take care of additional alternators which would not look unfinished and incomplete until such time as the additional alternators might be installed.

The alternating current measuring instruments used are of a very interesting type, invented by the late O. B. Shallenberger, whose untimely death in 1898 was a most serious loss to applied science in electrical engineering. In their various modifications, these instruments constitute a complete series of indicating and integrating meters for single or polyphase alternating currents.

The 5000 H. P. Switch.—Fig. 16 shows the general arrangement and construction of one of the 5,000 H. P. two-way four-pole switches. Two independently operated pistons working in air cylinders placed back to back are used to open and close the switches. The current carrying contacts are of the ordinary blade and jaw type. In opening the switch when the moving blades leave the contact jaws, the arc, which would otherwise occur, is prevented by a shunt circuit having a considerable resistance. The small current which flows through this resistance is finally broken at auxiliary terminals of the plunger and socket type, the material used for these terminals being a certain quality of brass which does not readily arc. The non-arcing qualities of this material were discovered by Alexander J. Wurts and utilized by him in his well-known and valuable lightning arrester for alternating current circuits. Its utilization in these switches in combination with a shunt resistance is due to Mr. H. N. Potter. On the whole, these switches have been very satisfactory in operation. They cannot be relied upon to open the circuit under short-circuit conditions, and were never intended for that purpose. They have been used, however, to open the circuits when delivering large amounts of power, and they have done this successfully. Under test conditions they have repeatedly opened, without injurious sparking, currents exceeding 600 amperes per phase. In opening the circuit by this switch, under the conditions existing in service, no appre-

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ciable rise of potential occurs. This point has been thoroughly demonstrated, as it was deemed possible that in suddenly opening heavy power circuits of considerable inductance and capacity, momentary abnormal rise of potential might be experienced. That no excessive rise does occur has been conclusively proved by tests, the method used being to place in parallel with the switch a spark-gap, consisting of two sharp terminals separated by an adjustable and known space.

Automatic Circuit-Opening Devices.—In the original outfit of switching apparatus no fuses or circuit-breakers were used in the leads between the alternators and bus-bars, nor has experience ever indicated that they are desirable in these circuits. The leads from alternators to bus-bars are not long, and the potential is but 2,200 volts, alternating.

The conductors used have an $\frac{8}{32}''$ wall of vulcanized rubber, containing 30% pure Para, this insulating wall being covered by a heavy braid, treated with compound to exclude moisture. Those more recently put down, over this braid have also a braid treated with a fire-proof composition. With such insulation there is less danger of a break-down between alternator terminals and bus-bars than there is in the armatures themselves, and considering the uncertainty of action of any automatic circuit-breakers or fuses available at the time, it was decided, I believe wisely, to install nothing of the kind in the alternator leads.

As regards feeders, the arguments in favor of automatic circuit opening devices are much more weighty than in the case of the alternator leads, since occasional failures of cable in an extensive system of distribution are inevitable, and without automatic opening devices in the feeder circuits the entire battery of alternators connected to the affected circuit must be shut down in case of trouble. A serious effort was therefore made to provide suitable automatic circuit opening devices. No circuit breakers having been developed for this kind of service, fuses of a type furnished by the Westinghouse Company and unquestionably the best available at that time were adoptod. These fuses had some ingenious and excellent features, but in service ultimately proved a failure, and in 1898, after a year's experience in charge of operation of the plant, I removed all of them, and since then the plant has been operating without any automatic circuit-opening devices in the local distributing feeders at the power-house. Where the feeders enter the premises of the tenants using the power, fuses were ori-

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ginally used,and these have since been succeeded by circuit-breakers of which, several types are now in service. The fuse originally used in the feeders at the power-house is of aluminium, and is enclosed between two lignum-vitæ blocks, in which spaces for the three parallel fuse strips are cut out. The arrangement is a development of the expulsive type of fuse, vents from each of the three fuse chambers being provided, through which the vapor of the exploding fuse is expelled. The lignum-vitæ blocks are hinged at one end, and when closed are held together securely at the other end. When the blocks are in perfect condition, so that the only outlet for the gas formed by the explosion is through the vents provided for the purpose, they are effective, as was demonstrated not only by tests at Niagara preceding their adoption, but also by their action in commercial service. But in practice, owing to gradual shrinkage of the blocks the exploding gas sometimes reaches the terminals and the fuse fails to clear. It was found in practice that the fuse itself, which having exposed terminals is necessarily an imperfectly insulated link in the circuit, caused more trouble than it prevented, and its use was therefore abandoned. Until the work of placing the local distributing cables in properly constructed conduits was completed, about two years ago, short-circuits upon some of the local distributing cables occurred much more frequently than was desirable, and the local service was occasionally interrupted when it probably would not have been interrupted if automatic circuit-breakers, such as can now be obtained, had been in use upon the feeder circuits. Since the work of relaying the cables has been completed, however, interruptions of local service due to failures in cables have been extremely rare, and as there is no space conveniently available in Power-house No. 1 for the installation of feeder circuit-breakers it has not been thought wise to introduce them. Plans for Power-house No. 2, however, contemplate the use of automatic circuit-breakers, and since adequate space will be provided for the improved types now available there is every reason to believe that they will be successful. Marked progress in construction of circuit-breakers for high potential and large power circuits has been made since 1893. To this progress the experience and requirements of the Niagara Falls plant have in no small degree contributed, and some most interesting and instructive tests of automatic circuit-opening devices have been carried out jointly by engineers of the manufacturing companies and the staff of

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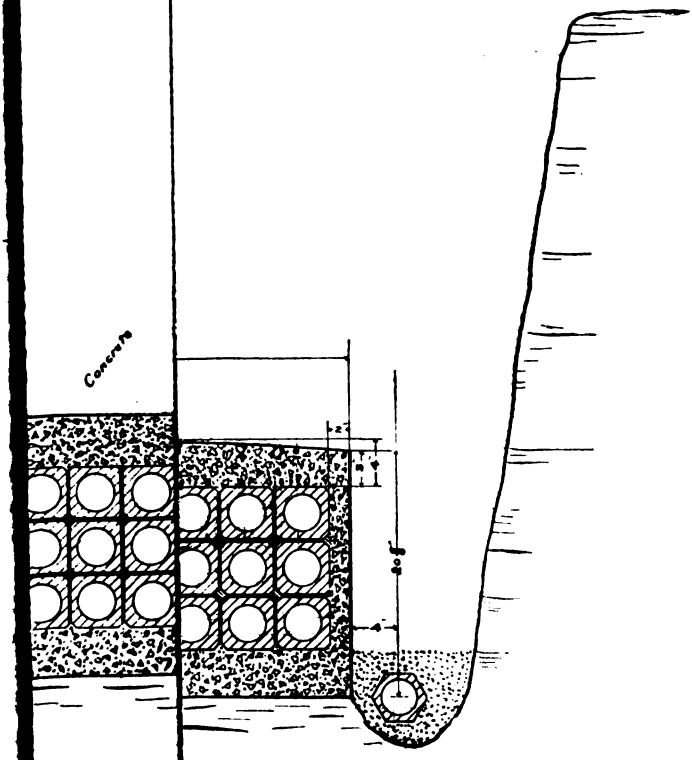

CTION-B C
Fig. 18.

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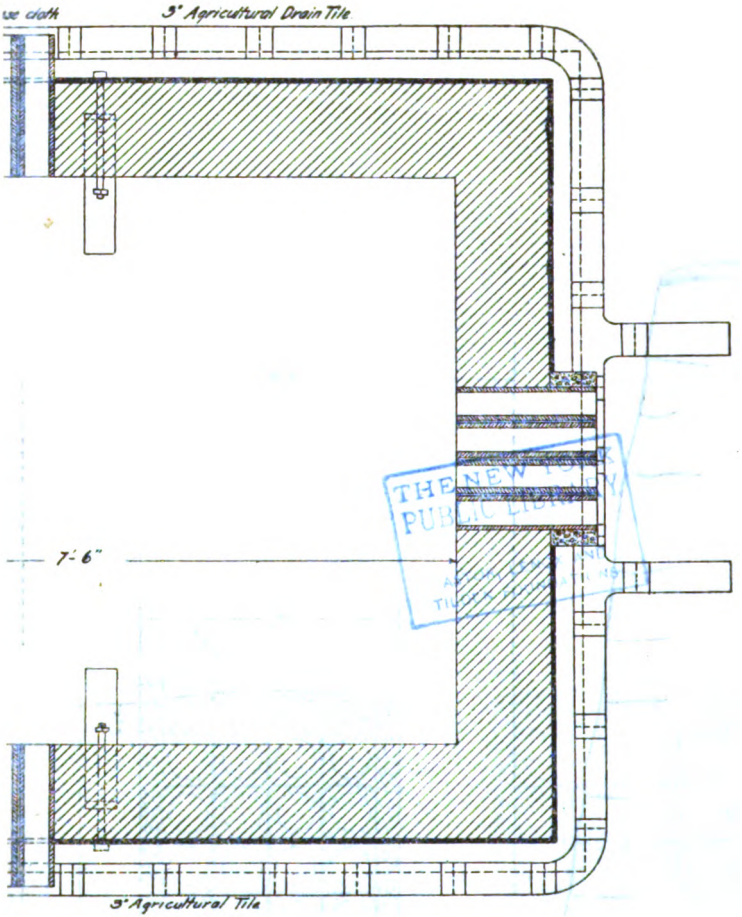

HORIZONTAL SECTION

FIG. 22.

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the Niagara Falls Power Company. I regret that the limits of this paper do not permit discussion of some of these tests.

Fuses and Circuit-Breakers on Long-Distance Transmission Circuits.—With regard to the circuits used for transmitting power to Buffalo and other distant places, the original outfit of switching apparatus in the power-house included fuses of the expulsion type above described. These fuses were located in the switch-room, and were mounted and connected exactly as are those used in the local distributing service—all feeder circuits, in fact, being treated alike in this respect.

When I became Electrical Director of the Cataract Construction Company and the Niagara Falls Power Company in March, 1897, the Buffalo service, which then amounted to less than 2,000 H. P., was supplied at 11,000 volts over transmission circuits which have been described by Mr. J. G. White in a paper read before the National Electric Light Association in June, 1897. At Niagara three 930-K. W. step-up transformers, supplied by the General Electric Company, and of the well-known air-cooled type, were installed, two being in service and one held in reserve. The connections used were and still are the two-phase, three-phase arrangement. Lead fuses, mounted upon a marble panel, had been placed in the 2,200-volt circuit on one side of the step-up transformers and aluminium fuses, also mounted upon a marble panel and separated from each other by wooden barriers, were used in the 11,000-volt three-phase circuit.

In Buffalo, in a small room adjacent to the power-house of the Buffalo Railway Company, three 250-K. W. transformers, connected in delta, received from the transmitting circuit three-phase current at about 10,000 volts and delivered three-phase current at 375 volts to two rotary converters, which in turn delivered direct current to the circuits of the railway company. In the 11,000-volt circuits supplying the step-down transformers, aluminium fuses similar to those used on the high potential side of the step-up transformers at Niagara were inserted. There were no fuses between the step-down transformers and the converters, but circuit-breakers were used in the direct current circuits leading from the converters to the main bus-bars of the Railway power-house, to which power was supplied not only from these converters, but also from a number of direct-current steam-driven dynamos. The fuses thus arranged were found to be far from satisfactory, a short-circuit on the transmission circuits in Buffalo usually blowing every

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fuse between the point where the short-circuit occurred and the bus-bars at Niagara. Attempts to prevent this by so adjusting the size of the several sets of fuses in series with each other as to permit only fuses at Buffalo to blow in case of trouble beyond them, and the high potential fuses at Niagara to blow only in case of trouble on the transmission line between them and the Buffalo fuses, did not succeed. Moreover, the 11,000-volt fuses sometimes failed to clear without practically destroying their terminals and the 2,200-volt lead fuses, which contained a considerable quantity of metal, usually destroyed terminals and barriers, and continued to arc until the power was cut off.

As the long distance service increased in amount and power was supplied to other sub-stations in Buffalo and other places, the necessity of automatic circuit opening devices, which would localize trouble by opening branch circuits without opening the main transmission circuits at the Niagara end and so interrupting the entire long distance service, became very urgent and to meet these conditions the time-limit relay circuit breaker was devised. The first of these circuit breakers was designed in detail and constructed by the General Electric Company.

These circuit-breakers are essentially the well known General Electric railway circuit breaker without the secondary break and blow-out coil, the trip coil being wound not with the main circuit, but with an auxiliary 100-volt winding supplied from a transformer, the circuit being closed through this coil by a clock-driven contact. The magnet in the main circuit controls a stop device which releases the clockwork which may be set to make the contact and trip the breaker at the expiration of a predetermined time interval. The current carrying contacts of the breaker are shunted through long, fine fuses placed in cylinders of wood, which are provided with vents, or chimneys, through which the gas of the exploding fuse may escape. When the shunt fuse is properly connected to the circuits, these breakers open the circuit so far as has been determined without momentary rise of potential and usually without burning the current carrying contacts. It is necessary, however, to use great care in replacing a shunt fuse, as any failure to make a perfect connection of the shunt will result in the destruction of the breaker the next time it is called upon to act.

A number of these, and also a number of time-limit circuit-breakers as constructed by the Westinghouse Electric and Mfg.

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Co., are now in use in Niagara and in Buffalo. The essential feature of the time-limit circuit-breaker is the use of an adjustable time measuring device which is started when the current passing through the circuit-breaker exceeds a certain predetermined value and which is used to open a circuit-breaker at the expiration of a predetermined time interval. No matter how great the current passing through the circuit-breaker may be, it cannot open automatically until a definite and predetermined time has elapsed.

The diagram Fig. 9 illustrates the connections of the power circuits between bus-bars at Niagara and the feeder circuits radiating from sub-stations in Buffalo. The diagrammatic connections shown appear simple enough but the actual connections are necessarily very complicated. This will be realized upon inspection of Figures 10 and11, illustrating respectively the actual connections in the step-up transformer house and in the Buffalo terminal house, where the step-down transformers are located. In Fig.9 I have shown but two alternators with their switches, one feeder switch, one pair of step-up transformers, one group of three step-down transformers and a single group of step-down transformers in each of the five sub-stations. As a matter of fact, four and sometimes five alternators are used to supply the long-distance service. Eighteen step-up transformers are installed at Niagara. Three transmission circuits are available, and two are normally used. Seven step-down transformers are provided in the Buffalo terminal house and from this terminal house eight sub-stations, each containing from three to upwards of twenty step-down transformers, are supplied. A very large number of distributing circuits radiate from sub-stations in Buffalo. It will be seen at a glance, therefore, that so extensive a system involves necessarily a large degree of complication. Occasional accidents to the system in one part or another are practically inevitable, and since the system, overhead and underground, is interconnected, the problem of localizing trouble resulting from a failure of insulation or from other accident is a very difficult one. The attempt has been made to solve the difficulty by the use of the time-limit circuit-breaker, but up to date the results have not been entirely satisfactory. Failures, however, have been due to the circuit-breaking parts and not the time limit device which, in connection with circuit-breakers that can be relied upon to open their respective circuits, is unquestionably a valuable feature. Referring to Fig. 9, time-limit cir

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cuit-breakers should be set as follows: (1) In 22,000-volt circuits at step-up transformer house, the relays should be set to actuate circuit-breakers at expiration of about three seconds; (2) in 10,000-volt cables connecting transformers in Buffalo terminal house to sub-stations, they should be set to open in somewhat less time, *e. g.*, one second; (3) in distributing circuits from step-down transformers in the various sub-stations, they should be set to open instantly. If a short circuit then occurs upon one of the branch lines from a sub-station, the circuit-breaker in that branch should open instantly, cutting off the supply of power to the branch without interruption of service throughout the general system, but unfortunately no circuit-breaker can open instantly. This being so, when the short circuit on the branch occurs, the clock mechanism of the circuit-breakers in the 10,000-volt circuit at the terminal house starts as does also similar mechanism in the circuit-breakers of the high tension lines at Niagara. As soon as the circuit-breakers on the branch at the sub-station have cleared, which will happen in a very small fraction of a second, the relay tripping device in the 11,000 and 22,000-volt circuit-breakers becomes inoperative, and these circuit-breakers reset themselves automatically. If for any reason the circuit-breaker in the local distributing circuit which is in trouble should fail to clear that circuit, the clock mechanisms of the circuit-breakers in the 11,000 and 22,000-volt circuits will continue to revolve until one second has elapsed, when the circuit-breaker in the 11,000-volt circuit will open and clear the circuit. The breakers in the 22,000-volt circuit at Niagara being set for three seconds cannot yet open and they automatically reset themselves.

This, however, is theory rather than practice, as owing to failure of circuit-breakers to clear their circuits the operation of the time relay cannot be said to have accomplished its object as yet. But I believe, that circuit-breakers capable of opening these circuits, even under the extreme conditions prevailing when a branch is short circuited, will be developed, and that the time limit device in conjunction with such breakers will solve the problem. At the present time, owing to the failure of the 11,000-volt circuit-breakers at the terminal house and the 22,000-volt circuit-breakers at the step-up transformer house to clear their circuits, the time limit device is not used at these points.

That time and experience should be required for the development of circuit-breaking apparatus adapted to circuits con-

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veying thousands of horse-power at 10,000 and 20,000 volts is not remarkable. Indeed, it has been strongly urged that no attempt should be made to open the power circuits while conveying large working currents. In a paper on "The Electric Transmission of Power from Niagara Falls," read before the British Institution of Electrical Engineers November 9, 1893, the author, who at that time was Consulting Electrical Engineer to the Cataract Construction Company, speaking of abnormal momentary rise in electric potential says: "As to the cause of trouble mentioned above, I hold that it is a piece of culpable ignorance, ruinous to the machinery, if any one should ever on a large power circuit with alternating current suddenly break the circuit while current is passing. This practice is quite unnecessary, and has given rise to a large proportion of breakdowns of alternating current machinery." In my opinion, this view is one well worthy of consideration. The answer of course is that unless provision is made for breaking the circuit while current is passing it becomes necessary to shut down the entire plant supplying Buffalo, Tonawanda and Lockport every time insulation fails in any part of a vast system of overhead conductors, underground cables and transforming machinery installed throughout the extensive territory supplied from the Niagara plant. But if in opening a branch circuit in order to localize trouble and avoid an interruption of the entire service the insulation of important parts of the system be subjected momentarily to extremely high potentials it may be argued reasonably that it would be better practice to provide no circuit opening devices, aim to make the insulation of the entire system so perfect as to avoid any breakdowns, and when accidents did occur cut off the entire supply of power until the cause of trouble is removed. It has been my view that automatic circuit-breakers to localize trouble were essential,—that the problem must be faced and solved.

In 1894, the 5000 horse-power pneumatically operated switch was tested in opening circuits of high inductance, an adjustable spark gap being placed in parallel with the break and the fact was established that for the circuits used, which were thought to fairly represent the most severe conditions to be expected in practical service, this switch could be used without danger of abnormal momentary potential. As this switch does not suddenly open the circuit through which the current of perhaps 1000

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amperes is flowing, but opens it through a resistance arranged as a shunt around the main contacts of the switch, the result demonstrated by the tests is accounted for, and in fact the switch was designed on these lines, not only with a view to opening the circuit without damage to the switch itself but to do so without causing momentary rise of potential. Similarly, tests of fuses, enclosed in lignum vitæ boxes, provided with a vent for the escape of gas showed no abnormal increase of potential in breaking the circuit. At a later date, tests of carbon shunt circuit-breakers, which in opening the circuit draw a long arc of carbon vapor, were tested and no excessive rise of potential was noted; and at a still later date Mr. Steinmetz, at Schenectady, tested circuit-breakers of the type which open the circuit under oil, and he found no dangerous rise of potential. In the case of the tests at Pittsburg in 1894, and also in the case of tests by Mr. Steinmetz, the circuits opened were supposed to be thoroughly representative of extreme conditions to be met in practical service. It is apparently established, therefore, that the danger of causing oscillations of extremely high potential in automatically opening alternating current power circuits operating at 25,000 volts has been surmounted. Nevertheless, up to the present time experience with circuit-breakers at Niagara has not been satisfactory. The conditions are extreme and the causes of the failures which have occurred have been recognized and in some degree removed, but further improvement is to be desired, and I suggest that in the discussion of this paper those who have given special attention to the design, construction and use of circuit-breaking switches let the INSTITUTE have the benefit of their study and experience.

In aiming to secure satisfactory automatic control and separation of circuits in case of accidents, as I have said, the time element relay circuit-breaker was introduced for the purpose of localizing trouble by cutting off the branch circuit affected without interfering with continuity of service through other branches or supplied through the same trunk lines. In addition to this, the reversed current circuit-breaker was installed at the Buffalo end of the line for the purpose of automatically disconnecting from other circuits in that city any one of the overhead transmission circuits from Niagara which might become short-circuited. Reversed current circuit-breakers, I believe, were first used at Hastings, England, where they were connected in the

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circuit between alternators and bus-bars. Those which have been used in connection with the Niagara plant consist essentially of a circuit-breaker similar to those used for opening circuits under abnormal overloads excepting that the usual tripping coil is omitted and a tripping device actuated by reversal of current substituted. In one type, the tripping device is simply a motor, one element of which is energized from and is consequently approximately in phase with the bus-bars, to which two or more incoming circuits are connected, while the other element is connected into and is therefore in phase with the current traversing the circuit which under certain conditions it is intended to open. In another type, and one which is probably more certain in action because less affected by the radical displacement of phases which accompanies short-circuits, the elements of a Shallenberger meter are used, the disk normally tending to rotate in a given direction but being held by a stop when the current through the series element is normal. In case of a short-circuit on the line, the direction of current through the series coil is momentarily reversed, while that through the shunt coil, which is connected to the bus-bars, though shifted in greater or less degree remains in phase with the incoming circuit which has not been short-circuited; consequently the disk tends to rotate in an opposite direction, and, being free to move, revolves through a certain angle and closes an auxiliary circuit which opens the breaker. In three-phase circuits, the connections are complicated, and owing to the radical displacement of phases which occurs when lines are short-circuited, I regard none of these devices as thoroughly reliable, although they have some times acted satisfactorily.

X. Transmission and Distribution.

In the report of Prof. W. C. Unwin, Secretary of the International Commission, which in January and February, 1891, considered no less than 22 plans for the development of Niagara power, which had been submitted in compliance with an invitation from the Cataract Construction Company, it is stated that "There were two or three points of primary importance as to which the Commission came to a definite expression of opinion." One of these related to the distribution of power by electrical conductors and the language of the Secretary's report is as follows:

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"On a third point the Commission came to a conclusion which departed from the view taken by any of the competitors. They considered that it would be necessary to have a tunnel, or subway, in which to place the main electrical distributing conductors; in such a subway the conductors could be of bare copper, placed on insulators. If the conductors were so placed in a subway, the greatest facility would be afforded for erection, for repairs, for inspection and for cleansing and there would be the greatest security from accident due to lightning or rain or snow, or to provide against public wanton mischief. These considerations appeared to the Commissioners to be so important that they would justify the excessive cost involved in the construction of the subways, which, however, would probably not be great."

Beyond doubt, such a subway, if large enough to admit of proper spacing of bare conductors carrying 20,000-volt currents and supported upon porcelain or glass insulators, would possess the advantages pointed out by the Commission, but unfortunately its cost is so great as to be quite prohibitive, unless the power transmitted through it is very large in amount, *e. g.*, 50,000 K. W. However, at the outstart the company actually did construct a tunnel, or subway, about half a mile in length, extending from the power house to a point near the works of the Pittsburg Reduction Company.

This tunnel was designed by Prof. Forbes and has been fully described by him in his paper of November, 1893. He proposed to use bare copper conductors supported upon porcelain insulators and carrying 20,000 volts for both local and long distance work, but the alternators finally adopted being wound for 2,200 volts the subway has never been used as originally expected.

Quite apart from considerations of cost, its dimensions are too restricted, in my opinion, to permit satisfactory working with bare conductors at any such potential as 20,000 volts, but setting aside the question of practicability, its actual cost exceeds by not less than $50,000 a mile the cost of a pole line such as that erected by the company last year. At the present time, exclusive of the power used temporarily for lighting the Pan-American Exposition, about 12,000 K. W. are delivered in Buffalo at time of maximum load. The cost of a tunnel from the power house to the new terminal house in Buffalo, a distance of 23 miles, would exceed the cost of the new pole line by not less than $1,200,000 and the increased investment required, upon the basis of present business in Buffalo, would approximate $100 per kilowatt delivered at time of maximum load. On the basis of

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3,000 K. W. delivered, the difference in cost of tunnel and pole line would of course be 400 per K.W. delivered, and since at the outstart the company was able to contract only for some 3,000 K. W. in Buffalo, the reason why the directors decided to use overhead construction instead of a subway is sufficiently obvious. It is to be noted that the commercial feasibility of a subway for electrical conductors depends primarily upon the amount of power transmitted. Had it been possible at the outstart to contract for the sale of 30,000 kilowatts in Buffalo, a subway might have been practicable, but even then to allow not only for proper spacing of the cables, but for convenient and safe inspection and maintenance, it should have been made considerably larger in section than was the case with the comparatively short length actually constructed and this of course would have made it still more expensive. For local distribution, with its branch lines and ramifications, such a subway construction is entirely unsuitable. In 1893 cables that could be relied upon for working with 10,000 volts potential could not be procured and the company's decision to adopt an overhead construction for transmitting power to Buffalo was the only one justified by the state of the art. Since that time, manufacturers of cable have realized great improvement in quality and effected radical reduction in cost and coincidently with these changes the sale of power in Buffalo has steadily increased. It is expected, therefore, that the day will come when underground cables will be employed for this transmission.

The Local Distributing System.—With the details of the early evolution of the local system of distribution used by the company I am not familiar. In March, 1897, power was supplied to local tenants, whose works for the most part were located upon the land of the Power Company, in amounts approximately as follows:

The Pittsburg Reduction Co.	3,195	E.H.P.
The Carborundum Co.	1,000	"
Acetylene Light, Heat and Power Co.	1,000	"
Niagara Electro-Chemical Co.	400	"
Buffalo & Niagara Falls Electric Light and Power Co.	500	"
Buffalo & Niagara Falls Electric Railway	300	"
Niagara Falls & Suspension Bridge Railway Co.	250	"
The Niagara Falls Water Works Co	45	"
Hygeia Ice and Refrigerating Co.	40	"
The Cataract Power and Conduit Co.	1,000	"

The power used by the railways was delivered in the form of direct current at about 570 volts, three 500 H. P. rotary conver-

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ters with step-down transformers having been installed inside the power house for this purpose. With this exception, the entire output of the plant was conveyed through single-conductor cables of 1,000,000 c. m. section from the bus-bars of "switchboard No. 1" through the subway and bridge connecting the power house with the transformer house. A cross section of the bridge is shown in Fig. 24.

In the transformer house, those cables used for the long distance service were connected to the step-up transformers while beyond the transformer house power was conveyed to local tenants through single conductor lead covered cables, the majority of which were of the section above mentioned.

From the transformer house to a man-hole near the works of the Pittsburg Reduction Company the cables were carried through the subway tunnel, to which I have referred.

Iron brackets had been erected on each side of the tunnel at intervals of five feet and upon these a majority of the lead-covered cables were supported, although some of them had been simply drawn into the tunnel and rested upon the floor. A cross section of the tunnel is shown in Fig. 25.

There was no provision in the way of conduits for the cables which extended from the man-hole at the end of the tunnel to the works of the Mathieson Alkali Company, the Niagara Electro-Chemical Company and the Niagara Electric Construction Company. The cables leading to these works had simply been laid upon the top of the ground and extended across the fields to the several establishments supplied with power.

Naturally these cables, although not extending outside the limits of the company's property, were subjected from time to time to mechanical damage by reason of carelessness and malicious mischief, and the local service was considerably interfered with. The work of reconstructing and extending the local distributing system was therefore taken up and pushed to a conclusion, the system now used, except the subway, being second to none. As evidence of this, it may be mentioned that for the last two years interruptions of the local service, even momentary in duration, have been extremely rare. A brief description of the steps taken to effect this result may be interesting.

Pending the completion of proper conduits, the cables beyond the end of the tunnel were placed temporarily in wood boxes for mechanical protection, and following this tile conduits were constructed.

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For the double purpose of effecting removal from these boxes of the cables in use without interruption of service to the tenants and providing an alternative set of cables to the works of each tenant to be promptly substituted for the usual working cables in case of break-down, the company put down four 1,000,000 c. m. spare cables, making connections from these to the works of each of the tenant companies, who could be reached thus without prohibitive expense. In the works of each tenant company to which this relay cable was extended, four two-way, double-blade, single-pole switches, suitably mounted, were installed, the spare cable being connected to one set of terminals, while the cable ordinarily used by the tenant was connected to the other set of terminals. The leads from these switches to the electrical apparatus of the tenant company were connected to the middle points of the two-way switches.

The double-blade switches were so constructed as to permit either of the two blades to be independently transferred from one contact to the other, thus making it possible to supply the tenant from the cable ordinarily used, from the spare cable or from both at the same time. This arrangement is now in use, and is very effective. For transfer from one cable to the other in time of emergency, and for testing purposes the switches are most useful.

From the end of the cable tunnel, a 36-duct conduit was put down extending to a man-hole on Adams Avenue, immediately north of the works of the Mathieson Alkali Company. The section of this conduit is square, the three inch tile ducts being laid in six horizontal rows, each comprising six ducts. It is laid upon four inches of concrete and protected on the sides by two inches and on the top by about three inches of concrete.

During the summer of 1899 it became necessary to provide conduits and cables to connect the power-house with the new works of the Union Carbide Company, which are located on the land of the Power Company, at a distance of about 2¼ miles from the power-house, and it was decided to put down a trunk conduit having a number of ducts sufficient to provide not only for the Carbide Company, including its contemplated extensions, but also for other tenants who in future may locate in the same vicinity. For the Carbide Company, immediate provision was to be made to the extent of 15,000 H. P., with necessary spare cable.

The use of power by the Carbide Company, and by the majority of the tenants of the Power Company, does not vary

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from hour to hour between wide limits, as is usual in lighting or railway service, but remains almost constant. This fact, in connection with the very large amount of power for which provision had to be made, led to careful consideration of the subject of heat in the conduits and its probable effect upon the cables. Prior to this, my attention had never been particularly directed to the question of heat in conduits, but upon consideration it was at once obvious that the usual construction of a conduit comprising a considerable number of ducts is admirably adapted to prevent the dissipation of heat caused by the currents traversing the cables.

Failing to secure from the manufacturers of cables and ducts any definite information with regard to the relative temperature of different ducts in a conduit as affected by their location with reference to other ducts and the surrounding earth, an experimental test was made for the purpose of securing light upon the subject. The result of this test demonstrates the great importance of taking into account the dissipation of heat in cases where cables conveying large amounts of power are used. I quote from a memorandum prepared immediately following completion of the test:

"*Losses in Cables.*—The problem of dissipating the heat of the cables demands careful consideration, as no conduit conveying 25,000 H.P. at 2200 volts has ever been put down, and the losses are necessarily considerable. These losses are of two kinds: (1) Losses due to resistance of the copper conductors; (2) Losses due to currents induced in the lead sheaths.

If twelve 1,000,000 c.m. cables be used to convey 15,000 H. P. by two-phase transmission at 2200 volts, the current through each circuit consisting of an outgoing and return cable delivering 2500 E. H. P. (1865 K.W.) is 848 amperes. The resistance of the cable per linear foot is .00001035 ohms at 68° F. The loss of energy per linear foot of conductor is approximately 7 watts, and when a considerable number of such cables carrying this amount of energy continuously for twenty-four hours per day, are placed in tile ducts constituting a conduit as ordinarily constructed, it is evident that the problem of dissipation of the heat must be carefully investigated.

"With regard to the thermal drop between the copper conductor and the outer surface of the lead sheath, the difference of temperature of the lead sheath and surrounding air, in order that the former may give up the whole or part of its heat to the latter, the thermal drop through the wall of the duct, the effect of the proximity of other ducts, the thermal drop from the conduit (which is surrounded by cement) to the surrounding earth,

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the heat conduction of the surrounding earth—particularly when very dry—and the tendency of the ducts to ventilate themselves where opportunity is offered, through manholes, we have been able to secure no satisfactory data from manufacturers of cable or others. We have, therefore, carried out a somewhat elaborate test, using 24 ducts of our 36-duct conduit, between two manholes about 140 feet apart, and situated in the vicinity of the Pittsburgh Reduction Co.'s works. Through each of these ducts, a No. 6 "drawing in" wire has been drawn, and these wires have been connected together at alternate ends in such a way as to put eight wires electrically in series, the 24 wires thus constituting three groups of eight wires each. Through these wires direct current from the works of the Pittsburgh Reduction Co. has been conveyed in quantity sufficient to cause a loss of energy of from 5.5 to 6 watts per linear foot. The test has been continued for about ten days and nights, and during this time hourly readings have been taken of the current in each section, the voltage across each section and the voltage across each two adjacent wires of each section. The ducts comprising each of the three sections have been so chosen that all ducts of one section were adjacent to the earth on at least one side, four ducts of another section were adjacent to the earth on one side, while the other four were separated from the earth by at least one other duct, and the eight ducts of the third section were all separated from the earth by at least one other duct.

"Readings of temperature by thermometer were taken in the manholes and in the ends of the various ducts. The more important and accurate determination of the rise of temperature, however, was made at intervals by stopping the flow of current through the conductor and taking bridge measurements of the resistance of each pair of conductors after allowing an interval of from ten to fifteen minutes to elapse in order that the wire might assume the temperature of the air surrounding it in the ducts.

"The results obtained are of great importance. It is shown that when the loss per duct foot equals 5.5 watts, the rise of temperature of the air in the duct above the temperature of the earth surrounding the conduit may be as much as 80° C. This applies to ducts which are separated on all sides from the surrounding earth by at least one other duct. The rise of temperature in the case of ducts which are next to the earth on one side, is about 60° C., equals 108° F.

If we assume that the temperature of the earth surrounding the conduit may in the summer rise to 70° F., it follows that the temperature of the air in the inner ducts may go as high as 214° F., while the temperature of the air in the outside ducts would be 178° F. under the same conditions.

Coincidently with our test, Mr. Henry W. Fisher, Electrician of the Standard Underground Cable Co., of Pittsburg, at our suggestion, has been making tests to determine the ther-

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mal drop between the copper and the lead sheath of a cable, insulated with $\frac{6}{32}''$ paper insulation, and the thermal drop between the outer surface of the lead sheath and the surrounding air. From Mr. Fishers's tests, it seems safe to assume that the rise of the temperature of the copper conductor above the surrounding air in the duct, will not exceed 40° F.

Now, if to convey 15,000 H. P., twenty-four 500,000 c. m. cables are used, we find by calculation that when the temperature of the ground surrounding the conduit is 70° F., the temperature of the copper conductor will approximate 215° F.

This temperature is excessive. It may be reduced (a) by ventilation; (b) by increasing the size of the conductors. If we make the size of each conductor 600,000 c. m. we have the following results:

Loss per duct foot	3.675 watts.
Rise of air in duct	94° F.
Rise of copper conductor above air in duct	31° F.
Maximum temperature of copper conductor	195° F.
Total loss in cables — 24 x 11,500 x 3.675 watts —	1,014 K. W.

Considering these results simply with regard to the life of the cables as affected by the temperature attained, it is evident that the temperature is too high for rubber insulated cables and probably quite as high as can be permitted wisely if paper insulated cables be used. As an alternative to the use of single conductor cables, the use of three-conductor cables working at 10,000 volts and supplied through step-up transformers was considered and finally adopted."

Referring to this plan, I again quote from my memorandum:

"*Plan B. 10,000-Volt Transmission, Three-Conductor Cables and Sub-Station.*—In considering this plan, the size of the cables (three-conductor Clover-Leaf type) must be first determined.

$$\text{Total current per phase} = .58 \times \frac{11190000}{10{,}600} = 612 \text{ amperes.}$$

Using six three-conductor cables, the current per conductor = $612 \div 6 = 102$ amperes.

At a temperature of 150° F., using No. 000 conductors, the loss per conductor per foot = $102^2 \times .000075 = .78$ watts.

The loss per cable per foot = $3 \times .78 = 2.34$ watts.

The total loss in cables = $6 \times 11{,}500 \times 2.34$ watts = 161 K. W.

The above is based upon triple conductor cables, each conductor having a section of 167,800 c. m. The loss per duct foot (with this type of cable there is no danger of additional loss in lead) is very moderate, and the maximum temperature will be well within safe limits. As regards limitations due to heat, therefore (and also as regards the application of Kelvin's law of economy), it

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would be possible to use conductors of a somewhat smaller section."

Where the sewers are at sufficient depth to drain the ducts the section adopted is that shown in Fig. 17. At other points the sections shown in Fig. 18 and Fig. 19 are used. The former is decidedly preferable as regards arrangement of cables in the manholes, since with it the natural arrangement is to carry them in pairs on brackets on opposite sides, and for large cables two upon a bracket are much more conveniently handled than a larger number.

It will be noted that no duct in the conduit, as illustrated in Figs. 17, 18 and 19, is separated from the surrounding earth by more than one other duct. Figs. 20, 21, 22 and 23 illustrate the manhole construction adopted.

Bearing of the decision to use 10,000 *volts for local distribution to distances exceeding two miles upon question of potential originally chosen for the alternators.*—The decision to use 10,000 volts for local distribution at distances exceeding two miles from the power-house is in no way inconsistent with the decision reached in 1893 to wind the alternators for 2,200 volts. The alternator potential was chosen with reference, primarily, to the expected large use of induction motors without the interposition of step-down transformers. In a letter addressed to the Cataract Construction Company, September 30, 1893, I said:

"In the plan which we presented to your company in February last, we recommended a potential of 800 volts. The limit, under the assumptions which we then made as to the use of a large proportion of small motors, was selected because we believed it to be as high a potential as could safely be delivered to the armatures of motors without the interposition of step-down transformers. As we are now informed, it appears probable that the proportion of motors of less than 25 H. P. output will be very considerably less than we then supposed it would be and we are now, therefore, prepared to recommend a potential of 2,000 volts at the motors, believing that this can safely and conveniently be managed."

In my memoir of February 6, 1893, upon this point, the language used was as follows—referring to 800 volts:

"This potential is well adapted to a large part of your work in Cataract City. At a certain distance from the generating station, depending upon the cost of apparatus, cost of distributing circuits and the loss in these circuits, transmission direct from generators at 800 volts will become more expensive than transmission by raising and reducing transformers in connection with

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circuits carrying higher potential at this distance which until the cost of apparatus can be settled cannot be accurately determined; we should begin to use raising and reducing transformers in connection with a high potential in transmission circuits."

My object in introducing these quotations from the record is to anticipate and meet the opinion which I have no doubt will be held by certain theoretical engineers experienced in the art of constructing large power plants on paper to the effect that we erred in originally winding the alternators for 2,000 volts instead of 10,000 volts.

Transmission to Buffalo, Tonawanda and Lockport.—For transmission to Buffalo, as I have above pointed out, the subway, or tunnel construction originally suggested by the International Commission was deemed impracticable, and the company ultimately decided to erect overhead lines for transmitting power to that city and to other distant places.

The first pole line was constructed by Messrs. J. G. White and Company, and has been fully described by Mr. White in a paper read before the National Electric Light Association in June, 1897. The poles are of Canada white cedar, cut with sap in and squared at both ends. They vary in length from 35 to 55 feet, the longer poles being used at points where the line crosses railway tracks or public roads. They are set in the ground to depths varying from 6 to 8 feet, the depth of setting depending upon the length of the pole. The cross arms are of selected long leaf Georgia pine. They are 12 feet long and 4 in. x 6 in. in section. The poles are spaced about 70 feet apart except on moderate curves, where they are somewhat closer. In crossing streams and where the curves in the line are at all sharp, braced structures, consisting of two poles set about 22 feet apart and carrying instead of cross arms a horizontal cross piece of heavy timber, 4 in. x 14 in. are substituted.

This pole line was designed to carry 12 conductors of 350,000 c.m. section. Only six of these conductors, constituting two three-phase circuits, have been erected, and the three conductors of each of these two circuits were originally placed side by side on the upper cross arm. This of course located the three conductors of a circuit on the same horizontal plane. The distance between the central conductor and each of the two other conductors was 18 inches. The conductors of each circuit are spiralled in six sections to avoid unbalancing of potential due to

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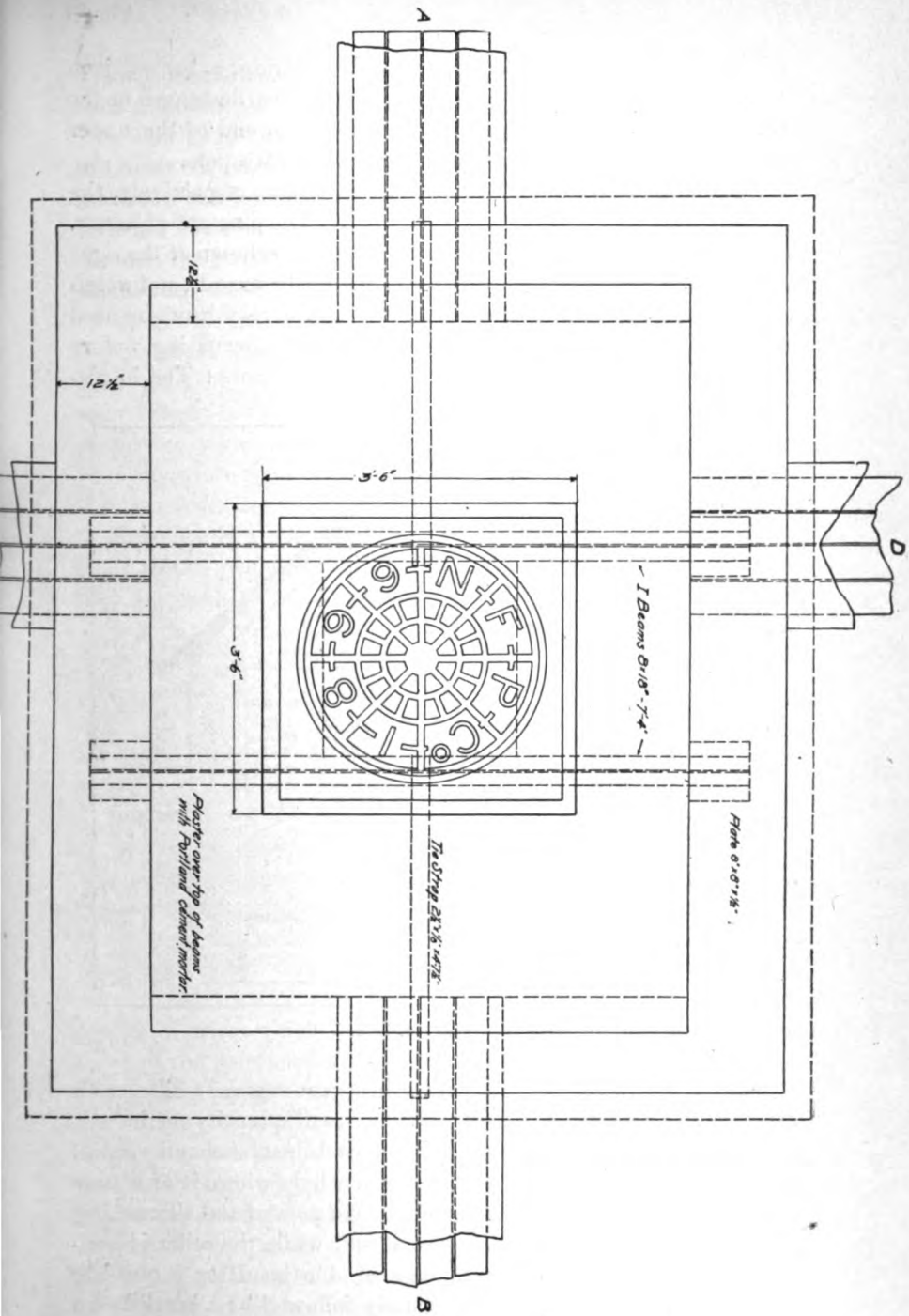

FIG. 23.—Plan.

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self-induction. As a protection against lightning, a barbed iron wire of the kind extensively used for fencing cattle ranges in the West was carried upon an iron pin near each end of the upper cross arm, this wire being grounded at every fifth pole.

Porcelain insulators of two types, designated, respectively, the Niagara type and Type "C" were used. The pins are of locust. A section of the Type "C" insulator and pin is shown at the right in Fig. 26. The conductors are copper, having 19 strands, and weigh a little more than one pound per linear foot. Every insulator used was subjected to a puncture test of 40,000 volts, alternating, before it was put in place. The method of test is as follows: The insula-

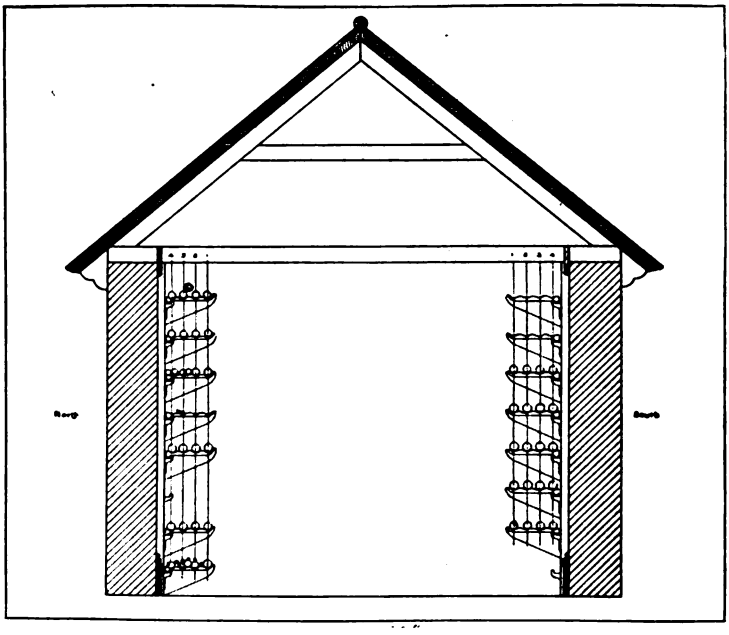

FIG. 24.

tors are inverted and set in a hollow iron pan which is filled with salt water to a depth of two inches. A small quantity of the salt water is poured into the pin hole of each insulator and a small metallic rod is placed vertically in the pin hole where it of course makes good contact with the brine. One pole of the alternating potential is connected to the metal rod, while the other is connected to the pan. Any weakness of the insulator is quickly manifested by a series of sparks usually followed by a breakdown

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of the insulator and blowing of the fine wire fuse included in the testing circuit.

In service the guard wires caused trouble by breaking and falling upon the charged conductors, thereby grounding and in some instances short-circuiting the latter. While neither snow nor sleet has has ever been observed to adhere to the charged conductors, the guard wires of course became heavily loaded with ice, and as they were not sufficiently strong were frequently broken by weight of ice and by wind pressure. Whether they were of any practical value in mitigating the effects of lightning is an open question. I am of the opinion that they were probably of some benefit in that direction, but the interference with continuity of service which resulted from them was intolerable and they were therefore removed during the summer of 1898. Obviously, if guard wires are used either for protection against lightning or to prevent other wires falling across a power circuit, they should be of ample mechanical strength to withstand all strains to which they are liable to be subjected.

Experience also demonstrated that it was a mistake to place the three conductors constituting a circuit on the same horizontal plane and only 18 inches apart as shown at the left in Fig. 27. I may be excused for disclaiming responsibility for this arrangement in view of the fact that in 1894, acting as Electrical Engineer of the Westinghouse Company, I submitted to the Cataract Construction Company elaborate plans and specifications for a transmission line in which the three conductors constituting a circuit were triangled, the sides of the equilateral triangle being 36 inches. These plans were rejected in favor of others and the arrangement actually adopted by the company proved very tempting to mischievous or malicious boys who repeatedly short-circuited the line by throwing across it short pieces of wire which they succeeded in lodging across two or more of the conductors. The resulting short-circuit continued to blaze along the line until the power was cut off at the Falls. The arc always traveled away from the power house. This, I presume, was due to the fact that when the short-circuit occurred the conductors affected between the power house and the point where the short-circuiting wire lay across the line, repelled each other and very possibly, owing to the natural swing of the conductors, were brought more closely together than usual in that part of the span which lay beyond the short-circuiting wire. The arc

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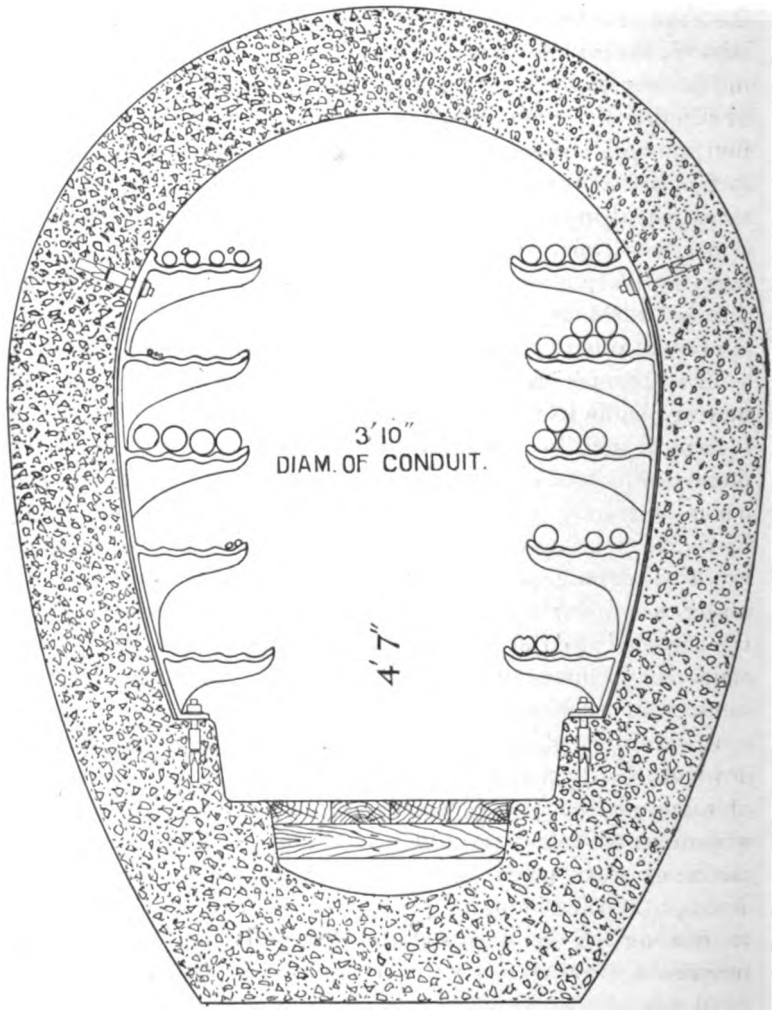

SECTION OF FORBES SUBWAY

FIG. 25.

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caused by the short-circuit was one of great intensity and at night the light was some times seen at distances exceeding half a mile. The conductors were afterward found to be considerably fused and in places little beads of copper projected from the strands. On one or two occasions, in trying to maintain the service and in the hope that the arc would clear itself, power was kept on the lines for some 20 seconds, but on these occasions one or more of the conductors was completely severed. The trouble was finally cured by triangling the wires, bringing them into the position shown at the right of the pole in Fig. 27. You will note that in this method of triangling, two of the conductors are carried on the upper cross arm while the third is carried on the lower cross arm. This arrangement is preferable to the more usual plan of carrying two conductors on the lower and one on the upper cross arm, since it is much more difficult for a mischief-maker to lodge a wire or stick in contact with two conductors.

The first pole line originally extended to a small terminal house located on the banks of the canal, near Albany street, in Buffalo, a point about two miles inside the city limits. In this terminal house the overhead circuits were connected to the cables used to convey currents to the various sub-stations in Buffalo, the apparatus in the terminal house comprising only lightning arresters and single-blade switches for changing connections of overhead and underground lines. These switches were not designed to open the circuits when power was being delivered, but were intended simply to facilitate changes in case of accidents causing interruptions of the service.

In the year 1900 a new terminal house about two miles farther down the river than the old one was erected, and the construction of a second pole line from Niagara was undertaken. The cable system in Buffalo was extended to the new terminal house, and the first two power circuits, designated, respectively, No. 1 and No. 2, which were carried upon the old pole line, were connected to the underground system at this point. It was decided to increase the potential on the overhead transmission lines from 11,000 to 22,000 volts, and as it was deemed impracticable to use 22,000 volts in the underground cables and at the same time was considered desirable to secure electrical separation of the overhead and underground circuits, step-down transformers having a ratio of 22,000 to 11,000 volts were installed in the terminal house. Switching devices providing for connection and disconnection of

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the overhead transmission circuits and of the underground cable circuits, together with an elaborate outfit of apparatus intended to protect the transformers against the effects of lightning, were installed.

The New Pole Line.

The new pole line differs radically from the old one. From Niagara to Tonawanda the length of span is doubled—that is to say, the average span in the new line is about 140 feet as against an average of 70 feet in the old line, these averages in both cases applying to tangents and not to the curved portions of the respective lines. The poles are similar to those used in line No. 1, but every third pole is substantially guyed. The unusually close

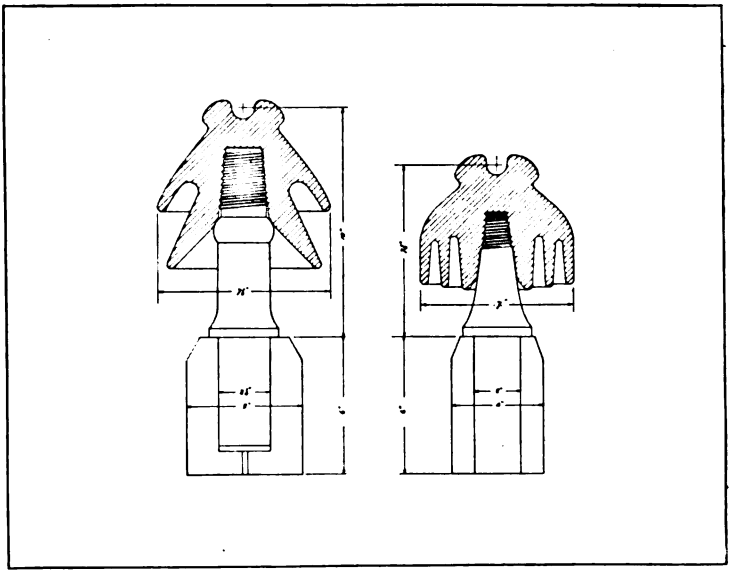

Fig. 26.

spacing of poles in the old line is explained by the fact that it was assumed that during sleet storms ice might cover the conductors to a radial depth of half an inch, which, if it did actually occur, would of course greatly increase the pressure, tending to overthrow the line during wind storms, which upon the Niagara frontier are often very severe. But experience during a number of winters has demonstrated the fact that ice never adheres to the power circuits while they are traversed by the working currents.

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This result is due in part presumably to the heating effect of the current and in part perhaps to static repulsion. It is certain that dry snow is statically repelled by the charged conductors, and I think it probable that this effect also helps in the case of sleety rain. In the case of the new line, calculations of the effect of wind pressure were based upon the projected area of poles, cross arms and conductors, but with no allowance for a covering of ice. Experience had shown that mechanically the weak point in the construction of the old line was the junction of pin and insulator, and for the new line a new pin and new insulator were specially designed. Cross sections of the old

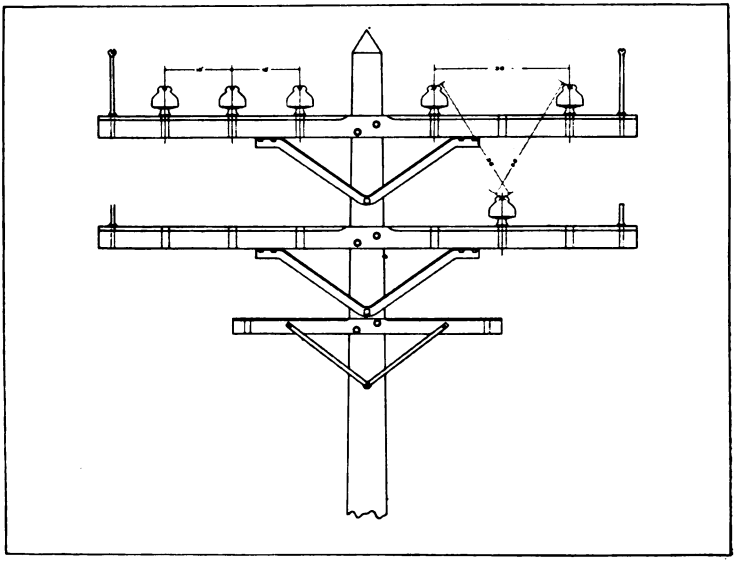

FIG. 27.

and new types are shown in Fig. 26. The old pin at the top is but $\frac{7}{8}''$ in diameter, while the new one is $1\frac{1}{2}''$. On the old pin but six threads engage with the threads in the pin hole of the insulator while in the new one nine threads are used. It is a singular fact that almost every power circuit hitherto erected in the United States has used an insulator pin of the same diameter at the top as the standard Western Union pin which was designed for a very different kind of service. Without going further into detail, it is sufficient to say that notwithstanding the fact that the length of span is doubled, the insulators

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of the new line are relatively much more securely fixed upon their pins than are those of the old line.

Tests were made to determine the horizontal strain which would break pin or insulator or both if exerted at the top of the insulator, *i. e.*, at the point where the pin rests upon the insulator. It was found that a pin will break at the point where it enters the cross arm under a pressure of about 2,100 lbs., which is about six times the calculated maximum pressure to which it will be subjected in service. The shoulder of the insulator will break under a horizontal strain of about 1,300 lbs. in service. The maximum strain upon the shoulder due to wind pressure against the conductor is probably never exerted at an angle of more than 45 degrees from the vertical, and against a pressure in this direction the strength of the insulator saddle is much greater than against a horizontal pressure such as that used in the test. The insulators, as regards quality of the porcelain, show a very marked improvement as compared with the best that could be obtained in this country a few years ago. Before being placed in position, each was tested in a manner similar to that which I have described for the insulators used on the old line, except that the new insulators, which have been designated Type E, were subjected to 60,000 volts, alternating. Under this very high potential, only about 3% of those furnished by the manufacturer proved to be defective. Of the last lot of over 400 not one failed under the test.

Aluminium conductors are used for the new line. The old and new pole lines follow the same route from the power-house to a point a short distance beyond Tonawanda where they diverge, the new line, from the point named to the terminal house, which is located just inside the city line at Buffalo, being approximately three miles shorter than the old lines. Taking into account the difference of the length of the line and in specific conductivity of copper and aluminium, the equivalent section of conductor for the new line works out about 497,000 c.m. The manufacturer guaranteed the conductivity of the aluminium conductor to be not less than 61% by Matthiessen's standard. The impedance of each circuit was calculated, and a section of 500,000 c.m. adopted for the aluminium conductor, which is of course a stranded cable. The line has been in use since April 1, 1901, and when operating in parallel with one of the old lines, the load is so equally divided that no difference can be detected by read-

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ings of the indicating wattmeters used. Where the aluminium conductor passes through that part of the company's territory where large chemical industries are established, it is protected by a braided cover treated with asphaltum. The principal reason for choosing aluminium instead of copper was its less cost, the aluminium line at the time when it was ordered costing about 12% less than an equivalent copper line.

In commercial use the line thus far has been eminently successful, not a single instance of an insulator breaking down in service having occurred.

The guaranteed maximum resistance of the conductor is .03472 per thousand feet and the minimum tensile strength is 23,000 lbs. per square inch, with average tensile strength of 25,000 lbs. per square inch. By calculation, with temperature of wire 20° F. below zero, the maximum strain upon the wire will be slightly more than half the minimum tensile strength. In erecting the line the sag was adjusted with reference to temperature of the air at the time of erection in accordance with a table based upon data set forth in the valuable paper upon "The Use of Aluminium Line Wire and Some Constants for Transmission Lines," by F. A. C. Perrine and F. G. Baum, read before this INSTITUTE May 18, 1900.

The joints are spliced and wrapped, but are not soldered. An interesting difference in the behavior of the old and new lines when the wind is blowing at high velocity has been observed. At such times, the tightly strung copper conductors of the old line swing or vibrate irregularly, but on the whole rapidly, and the strain caused by this vibration is transmitted to the insulators, pins, cross arms and poles in such a manner that the trembling of the pole may be detected by placing the hand against it at a point near the ground. Under similar circumstances, the aluminium conductors tend to assume a fixed position, which is sometimes apparently as much as 45 degrees from the vertical plane in which they hang when the air is quiet. There is practically no vibration perceptible at the pole. The elimination of vibrating strains upon insulator and pin is gratifying, as in the old line the tendency of insulators to work loose from their pins has been noticeable and I have no doubt that it has been caused by the vibration of the conductors during heavy wind storms. In connection with the construction of the new line the high potential connections of the step-up transformer house were radically

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changed by all these connections being brought up from an air chamber beneath the transformers, in which they had been placed originally, and supported upon "Type C" insulators carried by a frame work of hard wood and angle iron, as illustrated in Fig. 28.

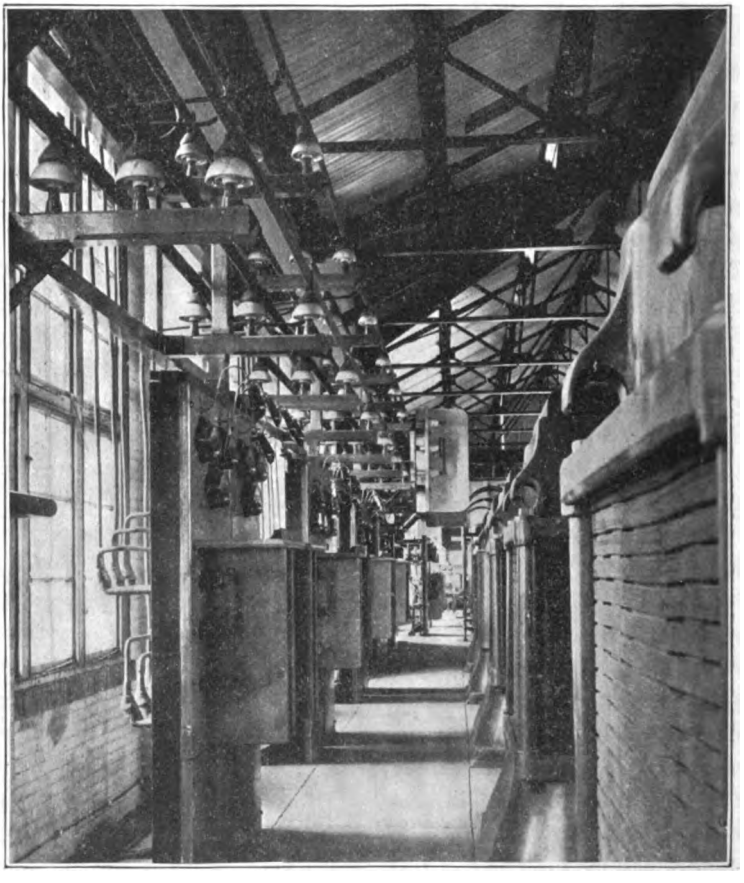

FIG. 28.

Present Output of the Plant.—In Fig. 29 the load curve for local service and for long distance service, as compiled from half hourly wattmeter readings for the twenty-four hours ending at midnight July 20, 1901, is shown. The local load varies between 14,200 K. W. and 15,700 K. W. This remarkable uniformity of output is explained by the fact that nearly all of the power used

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locally is delivered to manufacturing companies whose processes are continuous and whose use of power is practically constant. The long distance load varies from a minimum of 3,300 to a maximum of 15,600 K. W. Of this maximum, probably 90% is used for railway and lighting purposes.

XI. The Electrical Equipment of the Terminal House.

Power from Niagara is delivered to the terminal house at present by three overhead circuits, each of which is calculated to deliver the output of two alternators at the Falls, less the losses in step-up transformers and in the transmitting conductors. Two of the transmitting circuits are therefore ample for the present use of power in Buffalo, which does not exceed 14,000 K. W., except for about two hours in the evening, when it rises to nearly 16,000 K. W. The loss in step-up transformers is slightly less than

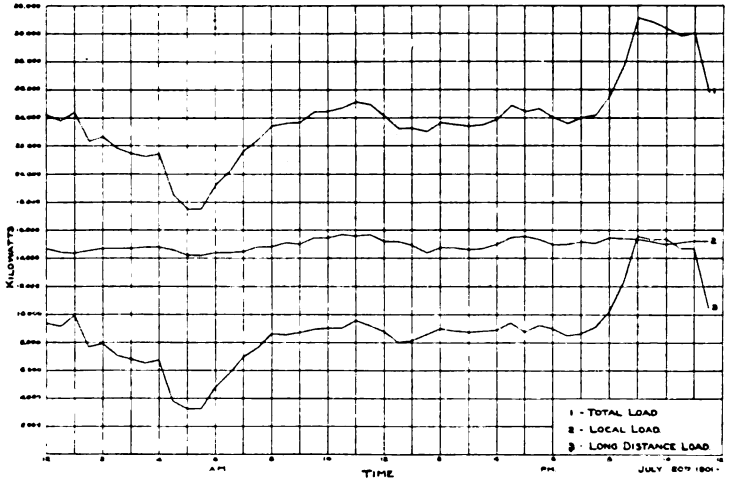

FIG. 29.

2%, and the loss in the transmitting circuits, when two of them are used to deliver the combined output of four alternators working under full rated load, is about 6%. If four alternators at Niagara deliver to the step-up transformers their full rated output, viz., 14,920 K. W., any two of the transmitting circuits operated in parallel will deliver to the step-down transformers at the terminal house about 13,750 K. W. Of this amount the step-down transformers will deliver to cables which convey power to the various sub-stations in Buffalo not less than 13,500 K. W. The net calculated efficiency of the transmission, including losses in step-

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up transformers, transmitting circuits and step-down transformers, when two circuits are in use under rated load, is therefore a little above 90%. About three weeks ago I had the pleasure of calling the attention of the President of the Cataract Construction Company to a copy of a letter addressed to him, under date of January 7, 1893, in which, in reply to an inquiry, I had made a statement of the efficiency that could be guaranteed for transmission from Niagara to Buffalo, and of showing him at the same time a letter from Mr. Philip P. Barton, Superintendent of the Niagara Falls Power Company, dated July 15, 1901, giving comparative watt-meter readings at Niagara and Buffalo during June of the present year. The efficiency promised in 1893 under conditions of line loss equivalent to those which actually obtained in operation during June last was 88%. Mr. Barton's letter states: "We have been receiving daily readings of the meters at the terminal house since June 1st. I am therefore able to give you a comparison of the total kilowatt hours delivered from our bus-bars with the kilowatts delivered from the secondaries of the step-down transformers at the distant terminals of the line for the month of June. This is taken from actual meter readings, except for the case of our Lockport tenants, in whose plants no integrating watt-meters are installed. The number of kilowatt hours received by these tenants has been carefully estimated from our knowledge of their average loads. The total number of kilowatt hours delivered from our bus-bars to our long-distance transmission circuits as shown by our feeder meters for the month of June is 6,504,000. The total number of kilowatt hours delivered from the secondary transformers in the terminal house, in the Tonawanda sub-station and in the plants of our Lockport tenants, as shown by actual meter readings in every case, excepting those of the Lockport tenants, is 5,840,100, thus showing a net transmission efficiency of 88.4%." During the month of June the transmitted load was carried sometimes upon one circuit and sometimes upon two circuits. I have calculated the losses in the lines and find that they averaged 6.5%. Of course commercial meters cannot be depended upon for closely accurate reading, but in this case the readings at Niagara were made by 10 meters and at the distant terminals of the line by 12 meters. It may therefore be assumed that errors are averaged, and that the result is probably accurate within 1%. By calculation, with 6.5% line loss, the net efficiency of step-up transformers, line and step-down transformers should be 89.5%

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Calculated results now show higher efficiency than those made in 1893, simply because the actual efficiency of the transformers is higher than that assumed at the time named. The very close agreement of calculated and measured efficiency will not be surprising to members of this INSTITUTE, but may be useful in answering the question often asked, whether results based upon electrical calculations are realized in practice.

The power, which is delivered by overhead lines to the terminal house of 22,000 volts, is reduced in potential and delivered to underground cables at 11,000 volts by two groups of transformers connected in delta. The rated output of each transformer is 2,250 kilowatts and three transformers are therefore capable of transforming the full amount of energy which two alternators and eight step-up transformers at the Falls and one transmission circuit can deliver to the terminal house. In operation, all of the alternators used to supply Buffalo service are operated in parallel as are also the transmission circuits used and the two groups of step-down transformers, but in planning the general features of the terminal house installation the possibility of ultimately operating two or three more electrically separated sets of alternators, lines and transformers was kept in mind and the transformer unit was therefore so selected that a group of three correspond in output to one transmission circuit. In approximate figures 7,500 kilowatts (10,000 H. P. delivered in Buffalo call for two alternators, eight step-up transformers, one transmission circuit and three step-down transformers.

To light a city of nearly 500,000 inhabitants, to supply power for the entire street railway service of that city, to deliver an aggregate of many thousands of horse power used for a very great variety of purposes and at points scattered throughout a territory some eight miles long and four miles wide, to do all this by a system of underground cables which in turn receive their supply through overhead lines exposed to lightning, to the winter storms of the Niagara frontier and to wanton interference of mischief-makers, and under these circumstances to secure a delivery of power free from all interruptions and in every way satisfactory to the users, is by no means an easy task. The theorist may say, get rid of your overhead lines and construct a tunnel or subway, but this, as I have pointed out, is a commercial, if not an engineering impossibility, owing to its great cost, at least until the aggregate use of power in Buffalo becomes so

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large that the cost of the underground construction will no longer add to the cost of power at Niagara an amount so great as to render its cost in Buffalo commercially prohibitive. The practical man may say, "You are attempting an impossibility; it is not reasonable to expect that you can tie to one central source by electrical connections, sensitive as human nerves, every industry that employs power in Western New York, expose these electric nerves through half their length to lightning and storm, expose them again in half a dozen sub-stations in complicated switch gear to the manipulation of a large number of attendants and then expect to get along without frequent attacks of temporary paralysis." But if such a view be accepted, progress is impossible. It must be frankly admitted that up to the present time the results of efforts put forth to make the service absolutely continuous and reliable have not been entirely satisfactory, but the creation of a system that shall in a perfectly satisfactory manner distribute throughout a territory so extensive and so complex in its requirements the surplus power of the Falls is necessarily an evolution requiring time. Very substantial progress has been made; apparently not many difficulties remain to be surmounted.

The equipment of the terminal house by the Cataract Power and Conduit Company will make it possible to introduce improvements in the system of distribution in Buffalo which may be reasonably expected to eliminate certain causes of trouble.

The system of distribution in Buffalo has been recently described in a very able paper[1] read before the INSTITUTE by Mr. H. G. Stott, and I shall not attempt to describe it here. With the terminal house equipped, the supply of power to sub-stations in Buffalo presents to the Cataract Power and Conduit Co. exactly the same problems that would have to be met were a central power house using steam driven alternators substituted for the terminal house, except that on the Niagara side of the 10,000-volt bus-bars, step-down transformers, transmission circuits and the power plant at Niagara take the place of the alternators and steam plant.

The local system of distribution at Niagara is probably as perfect as any in existence and there is every reason to expect that when the extensions and alterations in the cable system and in switch gear at sub-stations, which are now made possible by

1, TRANSACTIONS. vol. 18, No. 4, 1901.

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the installation of the terminal house equipment, are completed, the distribution of power in Buffalo will be thoroughly satisfactory to all concerned.

At the terminal house, the protection of step-down transformers against the effects of lightning is extremely important and not altogether easy to accomplish. The apparatus installed for the purpose comprises lightning arresters, reactance coils and a new device which the Westinghouse Company has recently developed and designated by the name "static interrupter." The lightning arresters proper comprise spark gaps between Wurts non-arcing metal cylinders in conjunction with the usual ground wires and plates, but the arrangement of the spark gaps differs materially from that generally used hitherto, a non-inductive resistance being used in series with all of the gaps while a part of the gaps are shunted by a non-inductive resistance. This apparatus, which has been designated the "low-equivalent lightning arrester," has been fully described in a circular issued by the company referred to.

It seems reasonable to expect that the separation of overhead and underground lines by interposition of step-down transformers in the terminal house will obviate some of the difficulties which have hitherto resulted probably from the metallic connection of overhead and underground circuits. That the lightning arrester equipments at Niagara and at the terminal house are effective is evidenced by the fact that no transformer at either point has ever been damaged by lightning, although on several occasions the line has been struck so heavily that cross arms and even poles have been shattered.

XII. The Equipment of Power-House No. 2.

I do not propose to discuss in detail in this paper the electrical equipment now in course of construction in power-house No. 2. Shortly after preparing the general specifications for that equipment, I resigned my position as Electrical Director of the Niagara Falls Power Company to give attention to other enterprises. The company has been fortunate in securing the services of Mr. H. W. Buck as Electrical Engineer in charge of new electrical construction, and it is to be hoped that when the new plant is installed, he will describe in detail for the benefit of the Institute the modifications introduced as a result of experience and the results realized therefrom. Meanwhile, how-

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ever, without impropriety and without trenching upon the province of those upon whom will rest the responsibility of carrying out the plans thus far determined, and extending them to meet the requirements of future growth, I may outline briefly the more important features with respect to which the equipment of power-house No. 2 will differ from that of power-house No. 1.

The general organization of the equipment will differ in having all switch gear and measuring instruments located in one structure instead of in two separate structures. The ultimate equipment will comprise eleven 3730 kilowatt alternators, wound for two-phases and 2200 volts. Oil switches operated by electric motors in combination with spring mechanism will be used. The cable subway, which, in power-house No. 2 as in power-house No. 1 is parallel to the row of alternators, will be widened to an extent sufficient to permit installation of all bus-bars and connections except the vertical risers to the switches below the floor line of the power-house. Above the floor line and directly over the subway which is opposite the middle of the row of 11 alternators the switches will be placed in brick compartments, faced on the outside with white enameled brick. As in power-house No. 1, two sets of bus-bars will be used. The circuit from alternators to bus-bars passes first through a circuit-breaking switch with time-limit overload attachment and thence to terminals of a pair of oil circuit-breaking switches, non-automatic, by means of which connection is made to either or both sets of bus-bars. Pairs of switches similarly arranged are used for each feeder circuit, but these are automatic with time overload attachment. All switches are of the new type developed by the General Electric Company, in which the circuit is broken under oil, the four sets of terminals of each switch being enclosed in separate brick compartments.

Instead of instrument stands, a switchboard of blue Vermont marble, located upon an elevated platform about the middle of the power house, will be used to mount the indicating and measuring instruments. Below these instruments, and extending the entire length of the board, a distance of 70 feet, the small switches which electrically control the movements of the large switches in the alternating current circuits will be located and these will be assembled in connection with an organization of dummy bus-bars and connections in such a way as to constitute an exact diagrammatic representation of the actual existing

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connections of the power circuits. While the organization of switchboard apparatus in power house No. 1 is remarkably free from complication, experience in the operation of the plant has demonstrated the fact that in time of emergency the most skilful operator is liable to make mistakes. When something goes wrong, the operator has no time to draw diagrams nor even to think diagrams. At such times the eye is a quicker and more certain guide then the mind. I feel confident that the use of the diagrammatic operating switchboard arrangement will materially contribute to the safety and certainty of operation.

The regulation of the alternators will be much closer than that in the machines thus far installed. Their external appearance will be considerably changed by the removal of the bridges, this being made possible by locating the field collector rings on the shaft below the stationary armature and carrying the exciting current to the field by wires placed inside the hollow shaft. Some changes in the armature winding, aiming particularly to secure greater mechanical rigidity, have been made and the design adopted provides also for a change in the system of internal ventilation.

In other respects, the new alternators will not differ materially from the old ones.

As in the case of power house No. 1, exciting current will be supplied by continuous current machines driven by turbines, but in the case of power house No. 2 these will be located in chambers excavated in the sides of the wheel pit at the level of the turbine deck. Experience has shown that similar chambers in the old wheel pit are almost perfectly dry, and it is thought that the simplification of the hydraulic plant required to drive the exciters, which results from placing them near the bottom of the wheel pit, will reduce chances of possible interruption of service by reason of trouble with the exciter turbines and shafts.

I began this paper by saying that "The history of the Niagara Falls power plant is a demonstration of the ability of applied electrical engineering science to attain in commercial practice results predicated in large degree upon theory." What are the practical results thus far attained?

Briefly, the Niagara plant has contributed in no small degree to the development of a considerable number of important chemical industries, and is already the center of a prosperous and

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rapidly growing manufacturing community. It is lighting Buffalo, Tonawanda, Lockport, and Niagara Falls, and is operating the electric railway systems in the cities and towns named.

For the first six months of the current year, the output of the plant was 104,378,000 kilowatt hours. A steam driven plant, delivering the same output and using three pounds of coal per unit at the switchboard, would have burned in the time named 156,000 net tons of coal—more than 800 tons per diem.

The generating plant, including alternators, exciters and switch gear has been remarkably successful and satisfactory in operation. The cost of maintenance and repairs for the past two years has been less than one per cent., while maintenance and repair of the motive power plant, including turbines, governors, pen-stocks, shafts, inlet racks, etc., has approximated two per cent. The local distributing system also has proved satisfactory in service. The long distance transmission and distribution of power hitherto has been subjected to occasional interruptions, brief in duration but nevertheless seriously annoying. The separation of overhead and underground circuits effected by the use of step-down transformers in the terminal house, improvements in organization of the local distributing system in Buffalo now rendered possible by the installation of the terminal house equipment and the gradual elimination of weak points in the system justify the belief that the interruptions of the long distance service will become less frequent than in the immediate past, but until the time arrives when it shall be commercially feasible to use cables instead of overhead lines occasional interruptions of service are apparently inevitable.

I cannot close this paper without referring to the excellent work of the operating department of the Power Company. It is not difficult to plan upon paper an extensive system of interconnected and mutually dependent electrical apparatus which will work perfectly—on paper—but such an organization of apparatus realized in iron and steel and copper requires for its successful operation the utmost degree of systematic vigilance upon the part of a thoroughly organized and disciplined force of trained operatives who must not only be familiar with their routine duties but ready to act with promptness and certainty in time of emergency. The theorist who sits in his study, examining diagrammatic connections of an extensive electrical system, is usually able to work out a solution of any difficulties

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which he may imagine—he can see just what switches should be thrown and what new combinations should be made; if he makes a mistake in his first solution no damage has been done, and he may try again. But the operator on the switchboard controlling 50,000 horse power must do his work under conditions very different from those of the study, and he can afford to make no mistakes. It is high praise for the organization and personnel of the operating force at Niagara to say that of the various troubles that have occurred in operation those due to mistakes or to lack of vigilance constitute a proportion quite insignificant. This result has been largely due to the foresight and systematic methods and organizing ability of the Superintendent, Mr. Philip P. Barton, and to the prompt resourcefulness, technical skill and extraordinary coolness in emergency of the Resident Electrician, P. M. Lincoln. It is a pleasure to be able to thus publicly express my appreciation of the able assistance of these gentlemen during the years in which we have been associated in the work at Niagara.

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Discussion.

[In concluding his remarks, Mr. Stillwell invited discussion on the subject of interruptions of circuit, and on that topic spoke as follows:]

Mr Stillwell.—Several obvious improvements can be named. Among those that have been thought of is improvement in the regulation of the alternators. This will be provided for in the new machines, which I presume will be used ultimately for long distance service, while the older machines will be used for the local service. Another thing that has been tried is the time-limit circuit-breaker. We found by experience that fuses and circuit-breakers without some relay device that was adjustable were not discriminating, that a short circuit on a branch or a sub-station would interrupt the whole supply to the city. To get around this difficulty we have endeavored to use a time-limit device, setting the circuit-breakers on the branches from sub-stations to open instantly and those at the terminal house connected into the cables which supply the sub station to open, say, in one second, and those at Niagara controlling the transmission circuits to open in three seconds.

This plan, if the circuit-breakers work as expected, is a discriminating arrangement. If a short circuit occurs in a circuit distributing energy from a sub-station, the circuit breaker which controls that feeder cuts it off in a small fraction of a second, the time-limit mechanisms of circuit-breakers at the terminal house and at Niagara start, but stop again the instant the circuit-breaker on the distributing feeder operates, and consequently the circuit-breakers at the terminal house and at Niagara do not open. If for any reason the circuit-breaker on the distributing circuit from the sub-station fails to clear, the circuit-breakers at the terminal house, controlling cables which supply power to the sub-stations will open at the end of one second. The circuit-breakers at Niagara can open only in case the overload due to short circuit persists for three seconds.

This arrangement has worked in some cases, but the circuit-breaker problem, so far as our experience has indicated, has not yet been solved satisfactorily. Of course, it is a very difficult problem, as Mr. Steinmetz said yesterday, to deal with these very large amounts of power, comparable with the energy of the Empire State Express going at 60 miles an hour, but that is a direction in which we must make progress. We must get a circuit-breaker which will operate instantaneously, or as nearly so as possible, so far as the making and breaking parts are concerned. Then I think we must use a time relay device to discriminate, so as to localize our difficulties. Improvement in the regulation of the machines will help. Whether we can improve matters further by using more induction motors and not so many synchronous motors is a question that is certainly debatable.

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The converter in the case of a short circuit tends to protect itself and to hold on to a certain extent, because its load drops automatically when the potential supplying the converter drops. In our experience with synchronous motors, however, and with rotary converters here in Buffalo, at the end of a long line, where it is not only a question of drop in the alternator, but drop in the transmission circuits and in the transformers, they have always let go if the short circuit has been at all serious. I have felt that perhaps the induction motors would not let go. A drop of potential lasting perhaps a second or two might not cause the induction motors to stop, whereas it inevitably does so far as our experience goes, stop all synchronous machinery.

PRESIDENT STEINMETZ.—Gentlemen, I am sure you agree with me that we have listened to a very interesting paper, one in which Mr. Stillwell has brought before us the first time I think it has ever been done, a general review and description of the enormous work which has been done here in developing power at the largest of all the waterfalls in the world. In opening the discussion I should like to ask two questions of Mr. Stillwell for our information, one, referring to the wave shape of the alternators, the other, the efficiency. Now, I understand that the wave shape given in the paper has been taken with the machine in the factory revolving at very low speed. I believe it would be interesting to hear whether the wave shapes have ever been taken with the machine running under service conditions, that is at full voltage, full excitation, driven by the turbine at no load, and also at full load, perhaps also with loads of different character. The machines are of rather high armature reaction, and frequently the wave shape changes with the load in such machines.

Then, another point I think we should like to get information upon is regarding the efficiencies of the alternators given here in the paper. These electrical efficiencies, 98.1 per cent., are calculated by adding the losses. In the loss, however, the load loss is not counted. Now, it would be interesting to hear whether any tests have been made to determine these load losses of the alternators, and how much they amount to and what effects they have on the efficiencies. In alternators of high armature reaction the load losses are occasionally quite considerable.

I believe Mr. Stillwell will be very glad to discuss the various problems referred to in the paper with you and I hope we shall have a very interesting discussion.

MR. STILLWELL.—As regards the form of potential curve of the alternator, the result of the factory tests has been checked by an elaborate series of observations at the Falls which were conducted by Mr. Tingley of the Westinghouse Company, who may be present. These tests were made under varying conditions of load. Under non-inductive load and upon open circuit the curves agree very well with those obtained in the factory,

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under the conditions of a very low speed. For varying loads the wave was very considerably distorted.

In regard to the efficiencies that are set forth in the tables, the iron loss was carefully determined by driving the machine by direct current motor on open circuit. We have added to that iron loss 20 per cent. as the assumed increase due to distortion of the field in the armature teeth, and this amount is included in these losses which are charged against the machine in the table that I have given.

MR. BUCK.—Mr. President, this paper is so complete that there is little to add or to criticize in connection with it. The historical part is certainly interesting, for the reason that the history of the Niagara Falls Power Company has to a large extent been the history of electrical engineering during the past ten years, and it is also interesting as bringing before us to day the engineering point of view which existed ten years ago. It seems to me that electrical engineering owes a considerable debt to the Niagara Falls Power Company. Ten years ago electrical engineering was in somewhat of a chaotic condition. Few engineers agreed upon systems, and they were afraid of the alternating current. Polyphase systems were looked upon with considerable skepticism, and men with capital, who could be persuaded to put their money into such enterprises, considered the transmission of large amounts of power as being more of a theoretical than a practical proposition. Engineering at that time needed a large installation, similar to that at Niagara Falls to establish confidence and to serve as a precedent for engineering practice. The Niagara Falls Power Company adopted a frequency of 25 cycles. This was a very radical and important step, for at that time the prevailing frequency was 125 cycles and 133 cycles, and it was looked upon as necessary by engineers. The prevailing alternating generator voltage was 1100, and the Niagara Falls Company raised it to 2200, which has since been adopted as the standard for a great number of installations I do not recall the figures for the largest generators which had been built at that time, but they were comparatively small. The Niagara Falls Power Company jumped to a size of 5,000 h. p., demonstrating very forcibly that the large size units were practicable and economical. It also demonstrated the feasibility of transmitting enormous amounts of power, enormous in comparison with anything which had been transmitted up to that time. The system remained practically a standard since the time when it was proposed, which I believe was 1892, a very remarkable record.

MR. LINCOLN.—Mr. President, Mr. Stillwell has called attention in his paper to the method of delivering power to the Union Carbide Company, and in connection with that has called attention to the heat losses in conduits. What he says there about the installation of rubber cables in connection with the great loss of heat is something which requires considerable thought. He

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has called attention to the fact that the rubber deteriorates by heat continuously. There is, however, one other condition to be noted at Niagara Falls which also seems to be pretty hard on rubber cables, and that is where the rubber is subject to constant static strain. To state a concrete case: at the terminal of our 20000-volt lines inside the transformer house of the Niagara Falls Power Company we installed rubber cables having $\frac{9}{32}$ inch rubber on the outside and where it ran down the brick walls it was supported in porcelain clamp insulators, so that any leakage current had to go over the surface of about $\frac{3}{4}$ inch of porcelain as well as through $\frac{9}{32}$ inch of rubber before it reached the iron clamp holding the porcelain. A test of the rubber cable alone showed it was capable of standing at least 70,000 volts. I should judge that the insulation of the cable, plus the porcelain insulator as it was put in, would stand 100,000 volts. But that same insulation after a week's service, broke down under the normal strain of about 13,000 volts between line and ground. It has occurred to me that possibly this deterioration might be caused by the ozone which is generated by static strain, the ozone attacking the rubber. Of course, the experience I have had does not prove the fact conclusively, but it points in that direction, and I thought it might be interesting to refer to the members for discussion.

Mr. Sperry.—Mr. President, there is only a word I have to say and that is in reference to ozone. We are working with quite large amounts of ozone, and it will certainly attack rubber. A hose made of the best Para rubber, having, I think, a $\frac{3}{8}$ wall, will stand only about a day and a half when conducting atmospheric air charged with only $1\frac{1}{2}$ per cent. of ozone. So, doubtless, it is the ozone that we must look out for in rubber insulation where static effect is present, especially where the tension is high enough to cause silent discharge.

Mr. Perrine.—Mr. Stillwell has very properly called attention to the difficulty and the practical unreliability of temperature measurements either by resistance or by thermometer. With the thermometer we get a local temperature that may be correct, and with resistance we get an average temperature that is more likely to be correct, as an average. I have not the slightest doubt that our rules are in error in their form. I believe that the proper method in specifying for apparatus should take into account the highest temperature obtainable with the thermometer and the average temperature obtainable by resistance, and in any particular apparatus these should not differ more than a certain percentage. If we have a high, or even a very low, temperature ascertained locally by a thermometer, and a moderate temperature ascertained by the resistance, we know that the thermometer in these cases indicates that there are certain other points which are greatly different from the average, and I believe that this should be taken into account in our rules. I

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am very glad that Mr. Stillwell has called attention to this point at this time.

As regards insulator-pins—the absolute stupidity of always using Western Union pins was called to my attention more particularly in one case where one of our prominent manufacturing companies was installing a plant for high voltage. They purchased a lot of large insulators and a quantity of Western Union pins, and after the material was all bought and on the ground they found that the petticoats of all the insulators rested on the cross-arm after they were screwed down to the pin. Then for the first time they saw that it was necessary, sometimes at any rate, to design pins.

As regards the matter of protection against interference with long distance lines, which Mr. Stillwell has called to our particular attention, asking for comments. I do not know whether their principal trouble here is due to normal occurrences, such as short circuits on the line, and failure of machines and other apparatus or to intentional malicious interference. As regards the normal troubles, I think that much remains to be worked out in respect of machinery. We have perhaps heard enough about synchronous and induction motors, but I am declined to think that a more correct design of synchronous motor will hold on better than the motors commonly used. But that was not the point about which I wished to speak. In the experience that I have had, I have found that disturbances to long distance lines due to abnormal difficulties—that is malicious interference with the line, can best be overcome by the systematic and general use of the newspapers, inculcating in the minds of the people living along the line the knowledge that inteference with the line means not so much damage to machinery and harm to the hateful millionaire who has built the line, but danger to the operators in the station. We have for the protection of some of our long distance lines inserted articles from time to time in local papers, in which we called shooting at insulators and chrowing bale-wire over the lines intentional homicide if not cold-blooded murder; and by judiciously distributing such information we have found that there is actually a very material lessening of malicious disturbance.

I do not believe that Mr. Stillwell is correct in his assumption that the non-collection of sleet on the Niagara line is due to the static effect. I believe that it is almost entirely due to the heat effect, and the reason I have for that belief is that a number of years ago I observed a small line carrying current for a Thomson welding machine, passing over the roof of a rolling mill and through the steam from a non-condensing engine. The current in that line never amounted to enough to heat theline, but the potential was always present to a sufficient amount to make the static effect very marked, with the result that the water was, to be sure, repelled from the line, but the temperature of the wire not

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being sufficient to prevent the formation of ice, we had icicles from two to three inches long standing up in all directions around the wire. I have seen icicles three inches long standing straight up. And so, while the water is repelled, I believe that heat is the essential for the non-collection of sleet.

MR. STERN.—I would like to ask Mr. Stillwell if they have had any of the experiences with anchor ice, such as the holding back of the water supply for the penstocks, thus cutting off the power and minimizing the output to any extent during the spring of the year.

MR. STILLWELL.—As regards anchor ice, Mr. President, there is a great deal of it encountered at Niagara at certain times. Some of the hydraulic "doctors" have told us that we ought to cease operations under those conditions, but we found that impracticable. Consequently we have done something that none of them has approved, but which seems to be effective—we have simply lifted the racks and let the anchor ice go through the wheels.

There is only one thing further I should like to say bearing upon the discussion, and that is in regard to operation, and to answer a single question suggested by Dr. Perrine as to the classification of the causes of trouble. I have not the classification here—perhaps Mr. Barton might supply if he is present—but I did make a rough approximate classification awhile ago of the interruptions, and from recollection I think this was about the way it worked out. Interruptions from cables were responsible for about 30 per cent. of our total troubles, interruptions from failure of exposed contacts at switches, circuit breakers and elsewhere, for another 30 per cent. or thereabouts. These two put together make 60 per cent. and these we may hope reasonably to eliminate as the weak parts are broken down and removed. I wish to say that in doubling the potential recently from 11,000 to 22,000 volts the company naturally had very much more trouble than in the two years just preceding the change. These incidental troubles I expect will all gradually be eliminated. Errors in throwing switches by operators at Niagara and elsewhere on the system—and practically none of those was made at the power house, where we can have highly skilled operators,—caused 10 per cent. Where, as I said yesterday, you have 24 $50-a-month men throwing switches and attempting to harmonize synchronous machinery, you are likely to have at least 10 per cent. of your interruptions from that source. Outside interference caused about 10 per cent., and lightning about 20 per cent. Now, this is an unusually high proportion of damage by lightning. There was one storm in which the line was struck five times. I think five poles with their cross-arms were destroyed. There is nothing to do when this happens but to let go and start up again. Such an occurrence is abnormal, however. The troubles from the cables we may hope to decrease

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and upon that point I hope we may be able to gain some advice from our president and from other gentlemen who are pursuing the theoretical study of the harmonics, which I believe are responsible for some of our troubles; and we can also decrease them by strengthening our insulation, as experience shows us where it is weak. As to errors in switching, I do not believe it is possible to reduce them materially. I do not believe there is any operating force in existence better disciplined or more skilled than the one employed by the Niagara Falls Power Company.

As to outside interference, no attempt has been made to decrease it by the method suggested by Dr. Perrine, viz.; advertisement of the danger to operatives involved by such interference.

We have tried almost every means, including detectives and patrols and all that sort of thing. The only cause of trouble that we cannot practically get away from until we put down an underground system of cables from the Falls, is probably that from lightning, and the point where I think we can make the greatest gain is in keeping our potential wave through the whole system as near a sine as practicable.

PRESIDENT STEINMETZ.—Gentlemen, we have with us Dr. Perrine, who I know has given the problem of lightning protection on transmission lines, and the study of transmission lines altogether, a good deal of attention. I think we would be interested to hear from him his experience with lightning protection. I call upon Dr. Perrine.

DR. PERRINE.—I think, Mr. President, this is taking rather a mean advantage of me, because, riding down on the car Mr. Steinmetz asked what my experience was, and I told him comparatively little. My experience with lightning protection is really comparatively little. On the Pacific coast we have lots of long lines, and it is there that my experience has lain. While we de not have the severe storms that you have here we have the unusual record in California that there is no month of the year entirely free from lightning. The occurrences that Mr. Stillwell describes of lightning storms being so severe as actually to strike the poles, we have very little difficulty with, but our lines being long,—a ten mile is a very short one there, and they run on up to 25, 30, 40, 50, 80 miles, and two recent lines have been built, one of 144 and the other one of 54 miles —which two lines at present are partly connected together in operation from one of the stations, making a total transmission of 198 miles,—with such work as that you can realize the fact that while we do not have the difficulty that you have here of the severe storms being localized along the lines and the liability of striking poles, at the same time we do have great trouble from the induction on the line, due to lightning storms in the neighborhood, because a lightning storm in the neighborhood of a 200-mile line is not an infrequent thing; and for that

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purpose we use the same protection that you do here, of choke coils and lightning arresters between them. Mr. Steinmetz asked me whether I thought the choke coils really had any good effect. I told him that the only good effect that I really knew they had, was that they induced the owner of the line to buy more lightning arresters, because if you don't put in choke coils and indicate to him that more lightning arresters than a single set are necessary, he will say, "Well, I will buy one set, but that is all I will buy;" and we know that one set is never sufficient, whether a choke coil is in or not. In these long lines we have used some sort of guard line, generally a barbed wire thoroughly grounded at least as frequently as every fourth pole. The method of doing that is to put an iron plate under the bottom of the pole, and connect that with the barbed wire stapled to the top of the pole. The effect of that wire seems to be be to keep the line continuously discharged. In very dry air on long lines, where the elevation of the line varies all the way from practically sea level to 1500 to 2000 feet above the sea you will find severe charges on the line in almost all weathers, whether there is any lightning in the neighborhood or not, unless that line is discharged by means of some sort of spark gap or this barbed wire. If you have barbed wire along the line you can handle the line with practical impunity in almost all weather, that is, I mean, the idle line. If you have no barbed wire along such a line you will get knocked off your feet every time you touch the wire, even when there is no generating apparatus connected with it at either end; and while that constant potential, due to the dry winds blowing over the line and charging it with frictional electricity, may not be very great, it is nevertheless a potential high enough gradually, in time, to puncture the insulation of the machines; and now whenever there is a lightning discharge in the neighborhood of the line, and there is disturbance set up along the line, that barbed wire discharges it. Mr. Steinmetz asked me whether I thought smooth wire, being more reliable as regards its strength, would not be just as good as the barbed wire. I do not believe it would, because the barbed wire undoubtedly discharges the line when it is charged, as I say, due to the air moving over its surface. It is true that the barbed wire discharges a great space of air, and the fact that that line is dead when the barbed wire is strung over the pole might be due to the fact that the barbed wire discharges the line itself as well as the air, after the line has become charged. Lines protected in that way, with the lightning that we have had, are practically free from disturbance. There was one case of an exceedingly severe storm that swept north and south through our State, across our line, which was extending east and west, and our line, 46 miles in length, was the only line, telegraph, telephone or power line, in that neighborhood which was not interfered with; and during that storm my assistant

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watched the lightning arresters very carefully, expecting to see a great deal of fire works. He sat out on the roof of the transformer sub-station where the lightning arresters were nearly all one night waiting to see the fire works, and didn't see any. Nearly all the lines in the neighborhood were incapacitated, and I believe that in spite of the acknowledged disadvantages, and they are altogether mechanical disadvantages, there is no lightning protection we can give that is so good as the almost continuous lightning rod afforded by such a barbed wire. Now, when you have such occurrences as Mr. Stillwell describes, of an actual lightning flash striking a line, I am reminded of what our President said a number of years ago, in discussing, I think, a paper of Mr. Wurts. He said, "There are three kinds of lightning that you have to look out for. First, a lightning discharge in the neighborhood of the line, which your lightning arresters generally get rid of; second, a secondary flash that strikes the line, and that your lightning arresters will probably get rid of, though probably the lightning arresters will be destroyed; and, third, a direct flash which strikes the line, and then you have to trust in Providence and repair what is left of the station."

Mr. Stott.—Mr. President, in connection with this very interesting, and one of the most practical, papers we have had, a point comes up that it seems to me would justify a good deal of investigation and that is the fact of resonance being established. Apparently on the Buffalo transmission line now there are times when such conditions obtain, I have been informed, that with a ground on one of the lines arcs will be established between metallic points ten inches apart. Apparently, that is not the e. m. f. of a resonance which could come up to 100,000 volts or more. I know our President has been taking up the question of resonance very closely, and I think it would be very interesting to us to hear what his opinion is on these effects.

President Steinmetz.—Gentlemen, it is very difficult to say what is the cause of such high voltages appearing in lines which give strokes of a foot or so, because there are quite a number of causes; but, knowing that there is some interference, malicious or otherwise, on the system, I should be suspicious of this interference. It may be some accidental short circuit of the line, some boys throwing wire over, or some machine suddenly changing the load, or any other circumstance which abruptly changes the conditions existing in the circuit which gives rise to a resonance voltage practically unlimited, that is, limited only by the discharging distance from a charged wire to the next ground or return circuit; but the most prominent source of disturbance I should suspect would be an accidental short circuit, or it may be even a moderately high resistance short circuit, so that the current consumed by the short circuit would not be noticeable in the power house in a system of such enormous magnitude.

Mr. Clarence E. Gifford.—In connection with the visit of

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August 22d, which included one of the railway transformer stations, it is possible that an account of some difficulties at first experienced in these stations in regulating, also in starting rotaries after a shut down at times of heavy load, and the manner in which some of these difficulties were overcome may be of interest. It should be here noted that these interruptions generally came from causes outside the station, although at first they occurred frequently from the relay which trips the main line circuit-breakers being set for too small a load.

The rotaries are 400 k. w. three phase, the armature being single wound provided with contact rings at one end and commutator at the other, as was probably observed.

The compounding, which is practically perfect, is for constant potential at the machine, and the d. c. voltage is about 600 when current is being received by the static transformer at 10,500 volts, and 25 cycles. At a higher periodicity and consequent increased speed of the rotary, the d. c. voltage is higher in proportion to the main line or primary a. c. voltage, for evident reasons.

There have been numerous times, especially in the winter, when, during the middle of the night, the speed of the generators at the Falls was so increased as to " make Rome howl " at the transformer stations. The a. c. voltage would be generously kept up to 12,000 and sometimes rise to 13,000. Of necessity, on account of lamps at that time used in the cars—five 110 volt lamps in each series,—the rotary fields had to be weakened to the full extent of the rheostat, still giving a d. c. voltage of 600 to 625, with the car lamps lighting up like small arcs. The a. c. ammeter reading was, of course, disproportionate to the output of the rotary. In this current, the wattless component (so called) was certainly very greatly in excess of the power component, but viewed with regard to heating effects, phase displacement is plainly without influence.

So far as the attendants of the railway power stations are concerned their ability has been somewhat underrated, and the difficulties with which they have to contend have not been mentioned. Salaries as small as $52.50 are paid in this vicinity, but most of the rotary transformer attendants receive from $72 to $81 per month, which prices, although not especially attractive, yet permit men of fair standing in the profession to obtain practical experience in the operation of such machinery without any serious privation financially; and this has in some cases been done in this city.

From a preceding paragraph it will be seen that there are times when the proper regulation of the power factor is forced out of the problem by other considerations which are, for the time, imperative.

The "horse sense," however, of almost any careful attendant, has been found to cause him ordinarily to give such field regu-

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lation as results in the smallest reading of the a. c. ammeter. If he is ignorant of the effects of phase displacement he attaches even greater importance to proportionately excessive readings of the a. c. ammeter.

Rotaries are started as d. c. motors synchronized and thrown on to the power line. The method of starting by throwing directly on to the power line, the field circuit being open at starting and then closed after the machine is up the speed, should not be considered where other means are available.

Starting a large machine in the above manner seriously disturbs the system, and its d. c. polarity when thus started is entirely a matter of chance.

Each of the stations feeds one or more of its lines in common with another station. By plugging the circuit-breakers at both ends of the lines thus extending from one station to another, feed for the lines of a station temporarily closed down may be obtained from neighboring stations. Current for starting is also thus provided. Three of the stations, including the one having the steam plant, have now also each a storage battery of 2,000 ampere hours capacity, which may, if necessary, be discharged in one hour.

Previous to the installation of all but the first one of these batteries, the starting of a station at times of heavy load was a serious matter, as the voltage at the d. c. bus-bar was generally very low, sometimes dropping to 350 volts, fluctuating with extreme suddenness through a range of 75 or even 100 volts. The rotaries, as first installed, received current, in starting, from the positive bus-bar, through the positive switch, series field, armature, starting rheostat, back to the negative bus; the negative switch being closed after the starting rheostat was fully cut out. Synchronizing was of course done by regulation of the shunt field. This, however, with the series field winding acting in opposition to the shunt winding, was, when the voltage fluctuated widely and rapidly, an exasperating task.

Heavy switches shunting the series winding were finally placed on the machines. Previous to that addition, however, the writer had the following method adopted by several of the attendants, and it proved eminently satisfactory, even more so than the use of shunting switches, inasmuch as the latter offer some resistance, especially at contacts, and therefore do not entirely eliminate the effects of the series winding which is itself of very low resistance.

In case all machines in the station were shut down, and No. 1 machine was to be started first, the following course was pursued:

The equalizing switches (located on the machines) of both No. 1 and No. 2 machines were closed; this connected the positive brushes of one machine directly to the positive brushes of the other machine No. 2 machine for the time stands idle, its series field circuit, positive cable and switch, together with the equal-

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izer cable, serving merely the purpose of making connection from the positive bus-bar to the positive brushes of No. 1 (the machine to be started) at the same time leaving the series fields of No. 1 open circuited, and thus entirely inoperative. No. 2 positive switch is now closed, No. 1 positive switch being left open.

No. 1 machine is then started, by the usual means of the rheostat, as a simple shunt machine, and synchronizes beautifully under the most extreme conditions.

Variations of 50 volts produce extremely small variations in the speed of one of these machines when running as a d. c. shunt motor, while the variations in speed may be so great under the same conditions with the *old* method of starting, that only quick regulation and a cool head could prevent danger.

The positive switch of No. 1 is *not* closed until after the machine has been thrown on to the alternating line. At the moment of throwing power on the machine its connection with the d. c. line is *not* opened, as was necessary under the old method to prevent its loading up to the extent of blowing open the d. c. breakers.

As a *shunt* machine, it will pick up a load of 25 to 30 amperes. The fields are now regulated to reduce this load to about five amperes, and the positive switch then thrown in, when further regulation is made as desired.

To start one machine when the other is running, simply close both equalizer switches, leaving open the positive switch of the machine being started until after the machine is thrown into service. The process is otherwise the same as above described.

The above process absolutely avoids danger and is eminently satisfactory. The use of "shunting switches" is also said to give good results. In throwing a. c. power on a machine it is preferable to have the machine running slightly *faster* than it will be driven by the line, instead of *slower*; as a heavy armature in *dropping* into step will tend to feed the line, whereas the forced *acceleration* of an armature is apt to disturb the system to a greater extent.

The desired condition is, of course, easily obtained by increasing the speed of the machine while running as a d. c. motor, until it unmistakably passes the point of slowest fluctuation of the synchronizing lamps and said fluctuation again becomes more rapid. The speed is then slowly and continuously reduced to a satisfactory point where the fluctuations are still slightly above the slowest point, and the switches then thrown.

Any statements made in these notes concerning the operation of rotaries under abnormal conditions should not be construed as prejudicial to the use of synchronous rotary transformers as compared with motor generators, as, everything considered, the transformer is preferred.

The condemnation should rather be against the extreme con-

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ditions which arose from the improper handling of the generators at the Falls, which would seem entirely inexcusable.

PRESIDENT STEINMETZ:—If there is no further discussion on this paper we will proceed to the next topic on the program for to-day, which is the reading of Mr. Wurts' paper on the Nernst Lamp. This paper has been printed in the TRANSACTIONS and has been distributed several times in the last few days, and I am sure is in your hands.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 23d, 1901. President Steinmetz in the Chair.

DEVELOPMENT OF THE NERNST LAMP IN AMERICA.[1]

BY ALEXANDER JAY WURTS.

It was in 1897 that Mr. Henry Noel Potter, while in the employ of Mr. Westinghouse, at Goettingen, became acquainted with the Nernst lamp. Early in 1898, Dr. Nernst, Mr. Potter and an assistant came to East Pittsburg at Mr. Westinghouse's request and exhibited the new discovery. Mr. Westinghouse quickly recognized its great possibilities and directed the writer to prepare for its commercial introduction. A happy choice brought Mr. Marshall W. Hanks to my assistance. Mr. Potter returned to Goettingen to study some of the details of the work. In June, 1899, Mr. Edward Bennett joined us, as did also Mr. Frederick M. Goddard a month or two later, who had been assisting Mr. Potter in Germany, but unfortunately in December of that year, Mr. Goddard contracted a violent cold from which he never recovered. In February, 1900, Mr. Murray Charles Beebe joined us and in August of the same year, Dr. Max von Recklinghausen.

I have thus briefly introduced the characters who have worked upon the Nernst lamp in America and without whose names its

1. EXPLANATORY NOTES.—The Hefner unit of candle power has been adopted in this paper so that ready comparisons may be made with results obtained on the Nernst lamp in European countries.

Names of Parts in the Nernst Lamp:—The "glower" is the filament or light-giving body. The "ballast" is a steadying resistance connected in series with each glower. The "holder" is the removable piece containing glowers and heaters. The "heater-porcelain" is the porcelain disk in the holder immediately back of the heater. The "heater-case" is a small glass globe used in the six-glower and thirty-glower lamps.

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history would be incomplete; my only regret being that these gentlemen are not all present on this occasion to share in the pleasure of announcing to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS the results of our work upon the Nernst lamp.

THE GLOWER.

It is not my purpose to describe the details of our experiments, but rather to give the results of our work. Let us begin with the glower, so named to distinguish it from the filament of the incandescent lamp.

Our standard 220-volt glower is about 25 millimetres long and .63 of a millimetre in diameter. It is made by expressing from a die a dough made of the rare earths mixed with a suitable binding material, cutting the porcelain-like string thus made into convenient lengths, drying, roasting, and finally attaching lead wires. This sounds very simple, but the making of glowers is an art not easily acquired; it is the result of long and painstaking investigation, particularly with reference to the terminal connection between the glower and lead wire. This connection, as Dr. Nernst made it, consisted of a few turns of platinum wire wound around each end of the glower, the convolutions being finally pasted with cement. This forms a successful and effective terminal, but the shrinkage of the glower ends, away from the convolutions of platinum wire sometimes causes the contact to deteriorate, resulting in the weakening and early destruction of the glower near the terminal. In the Hanks terminal, these conditions are reversed. A platinum bead is embedded in the end of the glower in such a manner that any tendency to shrink on the part of the glower material can result only in tightening the contact and thereby maintaining intimate union between the platinum bead and the glower. It is, then, a simple matter to fuse lead wires to the embedded platinum beads.

The glower, as you all know, is a non-conductor when cold, becoming, however, a conductor when heated. It is also an electrolyte; but it may be fairly stated that this phenomenon is not clearly, if at all, understood. Oxygen, however, seems to be necessary, or at least desirable, for its successful operation. As might be expected, no electrolytic action is apparent when operating with alternate current. With direct current, the electrolytic action is quite marked, resulting in a black deposit on the negative end of the glower, which spreads gradually from

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the negative toward the positive terminal. As this deposit increases, the voltage of the glower changes somewhat, and the candle power and efficiency fall off, owing to the poor light-emitting properties of the blackened portion. The life of the glower on alternating current is about 800 hours; with the same glower on direct current, it is considerably less than this. There are, however, radical improvements being made in direct current glowers.

A glower burns at a higher efficiency in its own heat, that is, in a globe, than it does in the open air. We shall refer again to

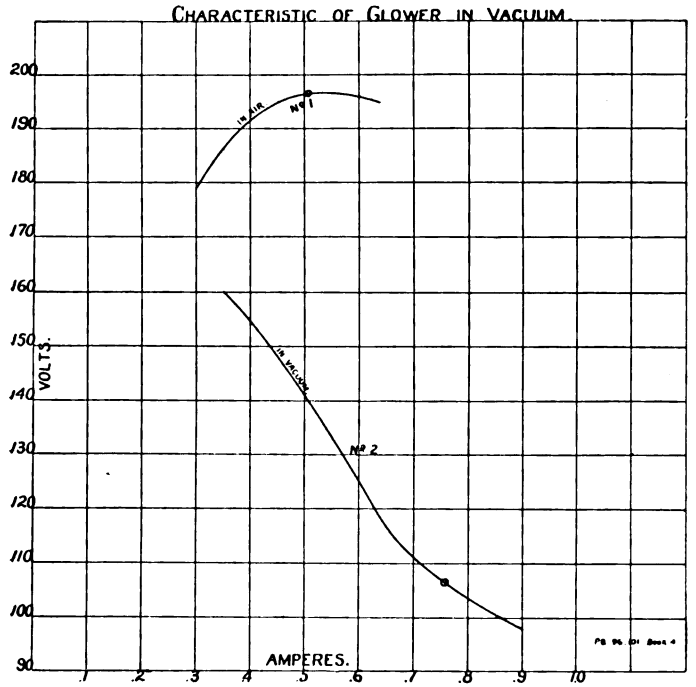

FIG 1.

this feature in connection with the multiple glower lamp. The glower is about as strong as a piece of porcelain of the same size, and it is difficult to break a short section. The terminals of a glower give off platinum black, which deposits on the globe; and although this cannot be wiped off with a cloth, it is easily removed in a variety of ways, so that the globe may be considered a permanent fixture in the lamp, and, for that reason, may assume fancy designs. When properly made, the voltage of a glower

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changes but slightly during its life, the tendency being to rise from two to four per cent. in 800 hours. For a short time before rupture, the voltage rises rapidly until the glower is broken.

The characteristic of a glower with reference to voltage and current is remarkable, and has given rise to the necessity of a steadying resistance. As the current in the glower is increased, the voltage across its terminals rises, at first rapidly, and then more and more slowly to a maximum, beyond which it again drops off with increasing rapidity as the current and resulting temperature through the glower continue to increase. Beyond the point of maximum voltage, the decrease in resistance of the glower is so rapid as to make the current difficult of control. In fact, without a steadying resistance, such a conductor would rapidly develop a short-circuit and flash out. The characteristic of a Nernst glower is shown in curve 1, Fig. 1, the small circle situated near the crest of the curve representing the point of 1.76 watts per candle in the open air.

In studying the characteristics of the glower and seeking for methods of operation under the best possible conditions, we naturally exploited the field in various gases including a vacuum, and although the experiments in this direction have not been exhaustive from a scientific standpoint, the results have been negative as far as practical results are concerned, and have demonstrated that for the present, at least, there is nothing to be gained in this direction. The vacuum curve and corresponding air curve are shown in Fig. 1. Aside from the fact that the vacuum has shifted the point of 1.76 watt efficiency to a much lower voltage and higher current density, it will be observed that all the points of the curve now lie on one side, giving a decreasing difference of potential for an increasing current. Such a condition as this involves the use of a relatively large steadying resistance, and renders the operation of the glower inefficient. Fig. 2 shows the nitrogen curve with corresponding air curve, and it will be observed, as in the case of the vacuum, that this gas has also rendered necessary a large steadying resistance and has thereby lowered the available efficiency of the glower. In Fig. 3, we have both the oxygen and hydrogen curves to compare with the air curve. It is interesting to note how closely the oxygen and air curves compare with each other, while the hydrogen curve shows characteristics similar to that of the vacuum curve requiring a large steadying resistance.

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There is an interesting phenomenon connected with glowers operating in a space free from oxygen, and which seems to be especially pronounced when operating in a vacuum. Where oxygen is excluded, the glower seems to be sluggish and to respond but slowly to changes in line voltage. The curves in Fig. 4 show this sluggish action in a vacuum. The line voltage is indicated by a dotted line in the upper part of the diagram, beginning with 270 volts. The upper solid curve shows the change of current value during a lapse of time indicated in minutes; while the lower curve shows the change in voltage on the glower during the same interval. Previous to this test, the glower had been run at .25 of an ampere for half an hour, after which the

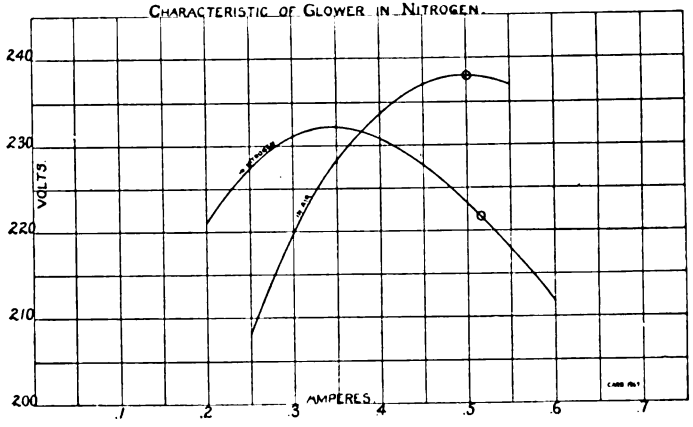

FIG. 2.

line voltage was raised 20 volts and the current values and differences of potential on the glower were taken at intervals for ten minutes, resulting in the curves shown. Shortly after the completion of this test, the line voltage was lowered 20 volts, when the glower again adjusted itself slowly to the new conditions, and returned to its original current and difference of potential. In air, the glower would have responded almost immediately to similar changes in line voltage. It is likely that the slight changes in both cases after the first minute are largely, if not entirely, due to the temperature correction of the resistance that was connected in series with the glower.

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Steadying Resistance or Ballast.

The advantage to be gained by the use of a steadying resistance which would enable the glower to be operated efficiently at a point on or beyond the crest in the characteristic curve, was well recog-

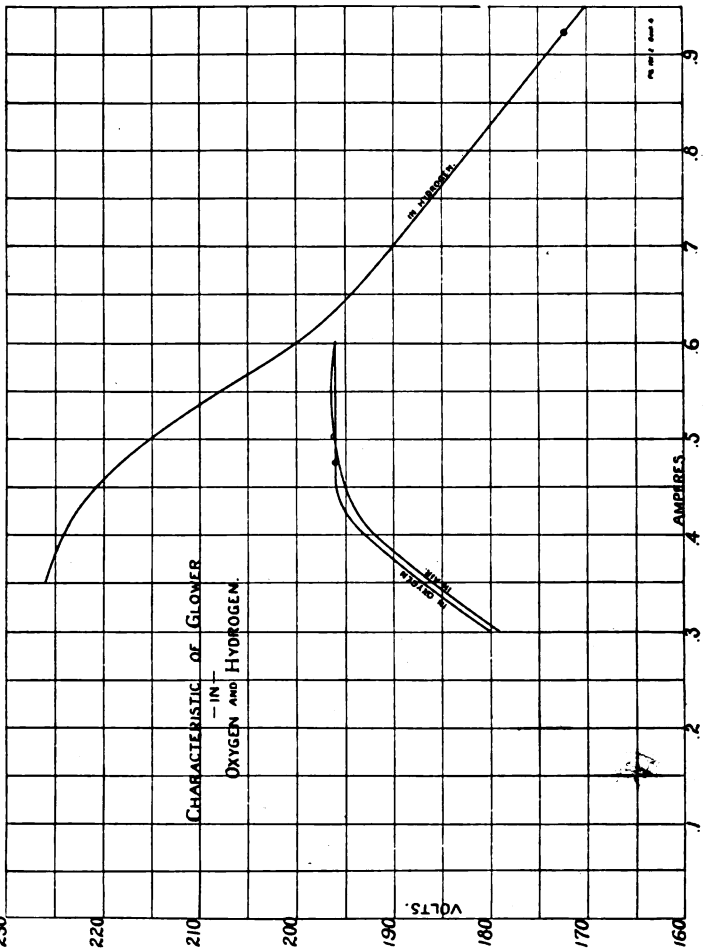

Fig. 8.

nized. To accomplish this under all conditions of commercial use, and with as little loss as possible under normal conditions, the steadying resistance should have as large a positive temperature correction as possible and this temperature correction should always be immediately available. For example, if the glower were operated on or beyond the crest of the characteristic, the

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current could obviously be controlled by a sufficiently large steadying resistance having no temperature correction, but such resistance would very materially decrease the net efficiency of the glower. On the other hand, if the resistance is assumed to have

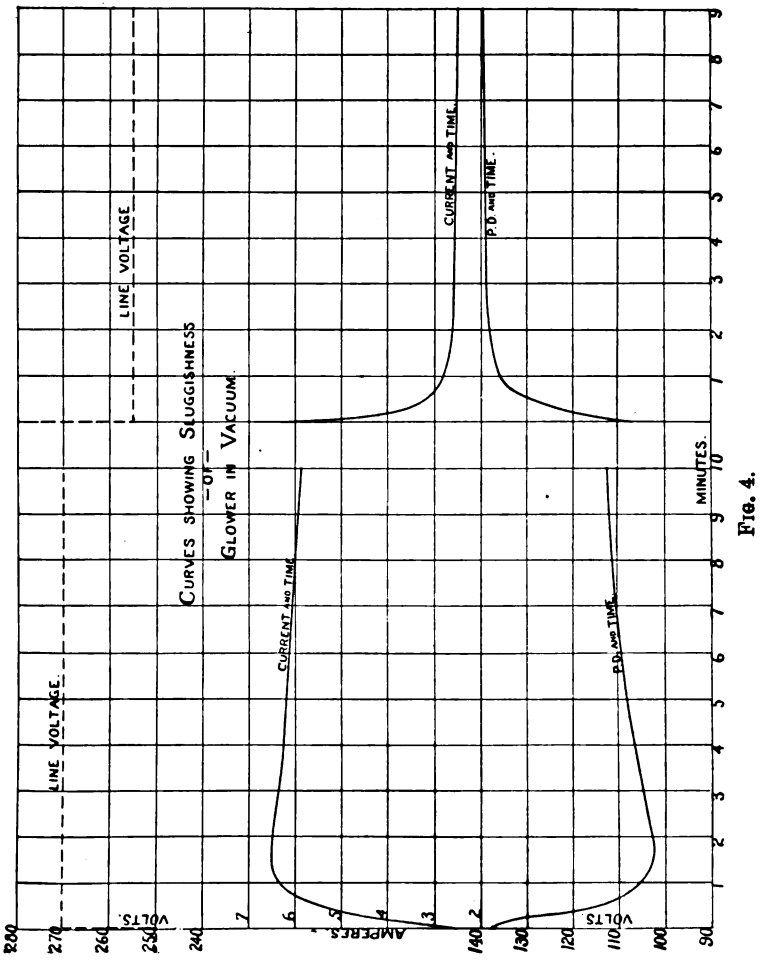

FIG. 4.

a high temperature coefficient, the necessary steadying resistance under normal conditions may be very much less than when no temperature correction is present, and then should there be an increase in electro-motive force above normal, the corrective power of the steadying resistance would be brought into play to check any abnormal flow of current through the glower; in other

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words, to take up the additional voltage. As already stated, however, the temperature correction should be *immediately* available, for if it were not, the glower would "shoot over" when lighting above the normal pressure, that is, take more current at the start

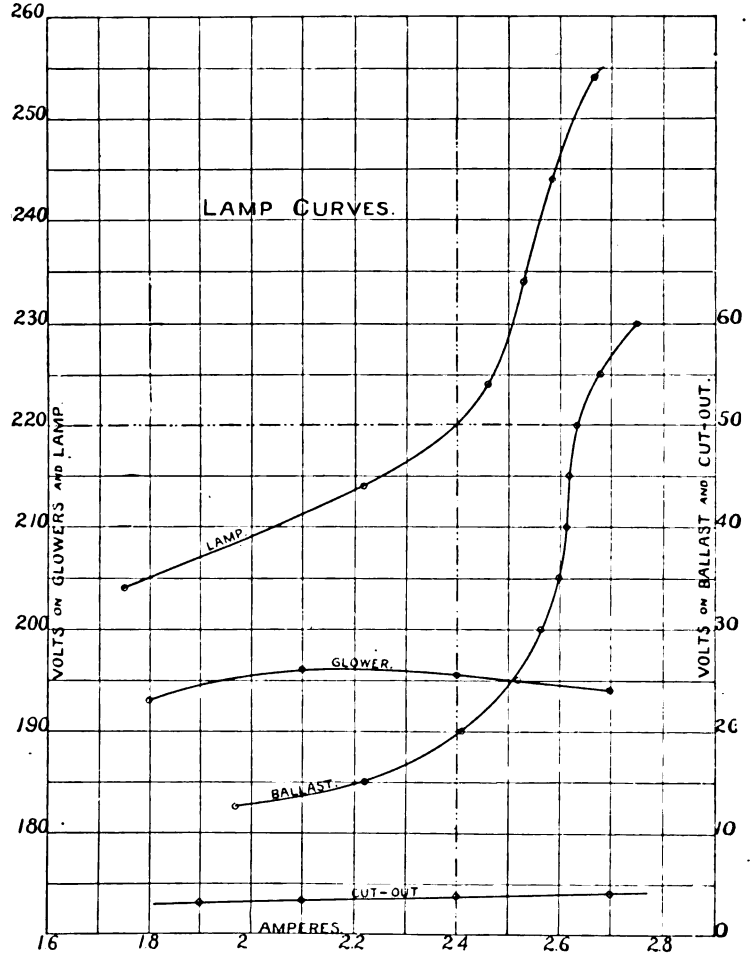

FIG. 5.

than it would a little later after the temperature correction of the steadying resistance had asserted itself. The same would also be the case with any sudden increase in the electromotive force applied to the glower, unless the corrective power of the steadying resistance were immediately available to check the current flow.

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Mr. Potter has designed a steadying resistance or "ballast," as he has named it, which is certainly unique in construction and which meets in a very effective manner, the peculiar requirements of the glower. Iron wire is used on account of its high temperature correction, and by properly mounting this in a small glass tube filled with some inert gas, he has secured a ballast having at once a high corrective power with minimum resistance under normal conditions and oxygen being entirely excluded, the wire can readily be worked throughout the entire high corrective region without danger of destruction. This remarkable characteristic of the ballast is well shown in Fig. 5, from which it will be noticed that for a 10% rise in current, the resistance of the ballast increases 150%, so that a glower thus protected becomes at once operative throughout a wide range.

The Heater.

As already stated, the glower is a non-conductor when cold, becoming, however, a conductor when heated. For practical service in a lamp, therefore, it is necessary that some means be provided for heating the glower and bringing it to a conducting temperature. This topic could well form the subject of a paper by itself, but time will permit me to review but briefly the developments made in this direction. Some of the lamps which Dr. Nernst brought with him from Europe were fitted with electric heaters, while others were intended to be heated by an alcohol lamp or even by a match. The further refinements of the lamp imposed new and severe requirements upon the heater. It is therefore especially gratifying that we can announce the construction of a simple, satisfactory and effective heater, suited to the requirements of the latest forms of the lamp. The glower is lighted at a temperature of about 950° C., and it will be readily apparent that to acquire such a temperature quickly and without rapid destruction of the heater and adjacent parts, renders the selection of the materials a very serious problem. Platinum for the heater seems an undesirable expense in a commercial lamp, and although many attempts have been made to devise a cheap mineral heater, platinum still holds its own as the least expensive, the most durable, and altogether the most desirable material for this purpose. The actual expense, however, is not so serious, because when the platinum heater is burned out, the value of the scrap is nearly 90% of the original cost, and as the labor is almost negligible, the running cost of the heater is small.

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As now constructed, the heater consists of a thin porcelain tube overwound with a fine platinum wire pasted with cement, the latter serving as a protection to the platinum wire from the intense heat of the glowers. These tubes are wound for 110 volts and are connected in pairs of two in series according to the service, the one, two, and three-glower lamps taking one pair, and the six-glower two pairs. These heater tubes are mounted on a porcelain support in such a manner as to afford easy access for repairs without removing the glowers. The life of the heater when running continuously is about 200 hours, or 133 hours

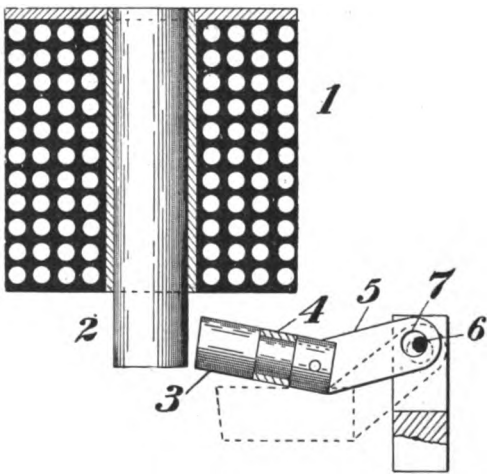

FIG. 6.

when the current is turned on and off 4,000 times at regular intervals. Inasmuch as the heater is not called into service for more than about 30 seconds to light the glowers, this would indicate a practically infinite life. In actual service, however, the heater remains in close proximity to the glowers and the high temperature to which it is thereby subjected causes a material decrease in its life. Nevertheless, the life of the heater is surprisingly long, probably several thousand lamp hours. The average life, however, cannot be definitely determined until a large number of lamps heve been operated over a very considerable period in general commercial lighting.

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Cut-outs.

An automatic lamp requires a cut-out to disconnect the heater from the circuit as soon as the glower shall have lighted. This is another one of those details that Dr. Nernst developed and exhibited in some of his early lamps, but which we have sought to still further perfect and to adapt to the special types of lamp which we have constructed. The cut-out includes a coil, a moving member and a contact, all of which must function at a temperature of about 110° C. without possibility of failure. The coil must therefore be heat proof, the contact must not weld, and the moving member should not hum on alternating current. These requirements are severe, but they have all been met in a most effective and satisfactory manner by embedding the coil in cement, by making the contact of silver, and by suspending the moving member from a single point of support.

The latter feature of the cut-out is illustrated in Fig. 6; 1 is the coil; 2 the core; 3 the armature or moving member, which is round in section; 4 is a silver band which makes contact by gravity with two silver wires not shown, forming a V; 5 is a strip of sheet steel .007 of an inch thick, which is inserted into the armature and securely held by a pin; 6 is small steel rod or support for the armature; and 7 is a hole in the steel strip 5, somewhat larger in diameter than the pin 6, so that when the armature is attracted by the magnet, there is practically only a single point of contact between the strip 5 and the supporting pin 6. This construction has resulted in a cut-out which entirely avoids the humming sound so persistent in the ordinary types of alternating current apparatus.

Lamps.

The lamps thus far developed are indicated in the following table:

Candle Power.	Voltage.	No. of Glowers.	Style.
50	110	1	Indoor
50	110	1	Outdoor
50	220	1	Indoor
50	220	1	Outdoor
100	220	2	Indoor
170	220	3	Indoor
400	220	6	Indoor
400	220	6	Outdoor
2000	220	30	Indoor

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The main features are the same in all. The indoor lamps are provided with ornamental spun brass housings; the outdoor lamps with neat japanned cast-iron housings. Single glower lamps have single pole cut-outs, whereas all the multiple glower lamps are provided with double pole cut-outs, the reason for this difference being that the extremely high temperature in the immediate neighborhood of a number of glowers tends to establish leakage currents between the glowers and heaters, unless the latter be entirely disconnected from the circuit.

We will examine in detail the six-glower lamp as typical of all the others. This lamp is suspended from an eye-bolt which being removed, allows of immediate access to the inner parts. On removing the housing, we find that the ballasts are placed in a semi-circle around the cut-out, the arrangements of the parts being such as to make all easy of access. The connections are made with small aluminium plugs on the ends of the interconnecting wires which avoid the many familiar inconveniences associated with set screws. All the parts are mounted on porcelain; in fact, there is no combustible material whatever in the lamp. The heaters and glowers are attached to a removable piece or "holder," the design being such that the heaters backed by a porcelain disk are immediately above the glowers, resulting in the following advantages: Stagnation of heat from the heater, thereby lighting the glowers in minimum time; no shadows, nearly all the light being thrown downward where it is ordinarily most desired; stagnation of heat from the glowers whereby the latter are run in their own heat and therefore at a higher efficiency than they would otherwise. The glowers and heaters are attached to the binding posts of the holder by means of small aluminium plugs, so that the perishable members are always easily and conveniently interchangeable. The holder is provided with nine contact prongs, which, when the holder is pushed up into the lamp, automatically make the desired connections. These are shown in Fig. 7; 1 and 2 represent the line terminals; 3 the actuating coil; 4 and 4 the double pole cut-out; 5 the heater; 6 the glowers; and 7 the ballasts, there being, of course, one ballast for each glower. A small glass globe, called the "heater-case," is held by spring clamps around the glowers, the function of which is to retain the heat and thereby decrease the time of lighting as well as increase the efficiency of the glowers. In service, the "heater porcelain," which is the porcelain disk

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immediately above the heater, becomes coated with a thin layer of platinum black, unless measures are taken to prevent it, and this not only decreases the illuminating power of the lamp, but if not removed, will in course of time become conducting and cause leakage of current. No simple means have been discovered for

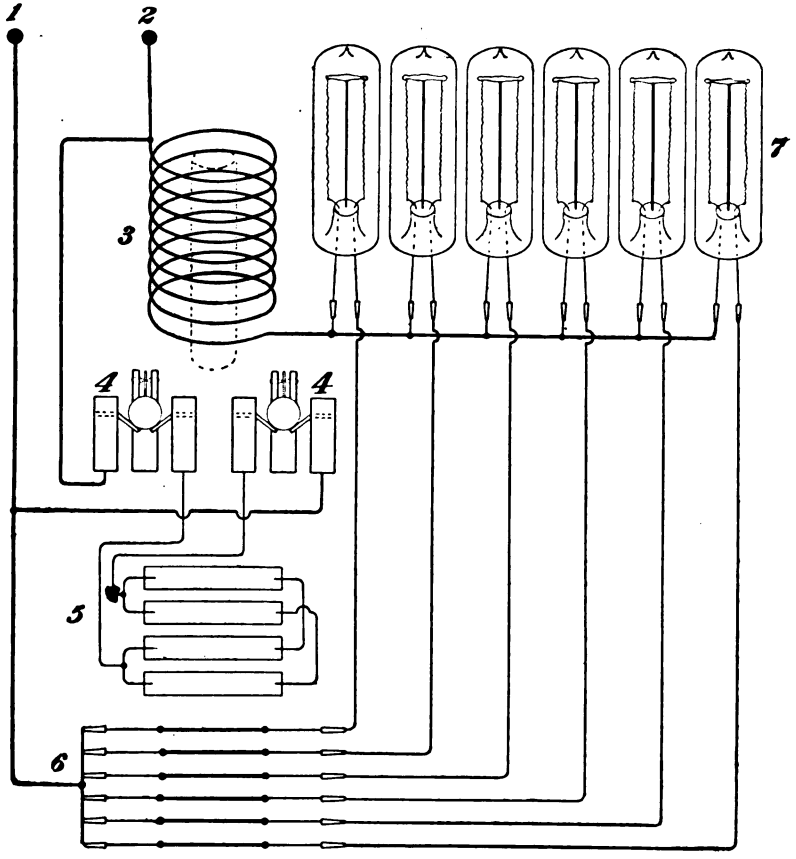

FIG 7.

removing the platinum black from the porcelain surface. This difficulty, nevertheless, has been avoided by coating the surface of the porcelain with a thin layer of white paste, which may be easily removed with a stiff brush or scraper. The platinum black now deposits on this coating, both of which may be removed together, leaving the fresh, white surface of the original porcelain to be recoated for further service; but even should the

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platinum black be allowed to accumulate, all danger of leakage currents is avoided by surrounding the holes through which the lead wires pass, by small annular rings or grooves, it having been discovered that the platinum black will not deposit in these small spaces; the continuity of the platinum black surface between the lead wires is thereby interrupted. For higher candle powers, the six-glower holder is used as a unit and this may be multiplied to any desired limit.

The quality of the light is remarkable for its beauty and close approximation to daylight. All colors are seen in their proper shade, making the light especially desirable in stores, art galleries, drawing-rooms and the like. The absence of shadow, the steadiness of the light, the simplicity and low cost of maintenance, the high efficiency of the lamp, and the fact that it is operative on 3,000 alternations, are features that will commend themselves strongly to the lighting world.

Efficiency.

It is not an easy matter to state the efficiency of a light, and the difficulties are especially pronounced in the case of the Nernst lamp. It would seem desirable, therefore, to give the results of various methods of measurement and comparison rather than to make any definite statement based on any particular method or set of readings. Referring, therefore, to the six-glower, 220-volt, alternating current lamp, from which most of the data has been obtained, we may note the following:

A 220-volt glower operating at its normal current of .4 of an ampere, requires 20 volts more in the open air than when burning with five other glowers in a three-inch globe. The lower voltage and consequently the improved efficiency, when multiple glowers are placed in a globe, is due to the fact that the glowers are operating in a highly heated atmosphere. The efficiency of the six-glower lamp with clear heater case, but without the dome shade, is 1.2 watts measured in the direction of greatest intensity.

A more satisfactory statement will be found in the accompanying table giving the spherical and lower hemispherical efficiencies of the six-glower Nernst lamp, together with the corresponding figures for alternating current and direct current enclosed arc lamps:

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					Mean Intensity in H. U.						Watts per Mean H. U.					
					Spherical.			Lower Hemisphere.			Spherical.			Lower Hemisphere.		
	Voltage.	Current.	Watts.	Power Factor.	Opal Outer.	Clear Outer.	Shade.	Opal Outer.	Clear Outer.	Shade.	Opal Outer.	Clear Outer.	Shade.	Opal Outer.	Clear Outer.	Shade.
6-Glower.	220	2.35	517	1.0	149*	—	147	240*	—	279	3.47	—	3.5	2.15*	—	1.85
A. C. Arc.	110	6.29	417	.6	130	159	152	—	190	254	3.21	2.62	2.49	—	2.23	1.48
D. C. Arc.	110	4.9	539	1.0	177	207	—	—	272	—	3.03	2.60	—	—	1.98	—

An opal inner globe or heater-case was used in all cases except the four readings marked *.
*A clear heater-case and sandblasted spherical globe were used.

The arc lamp figures were taken from the Report of the Committee for Investigating the Photometric Values of Arc Lamps, read before the National Electric Light Association in May, 1900. Examining this table, it will be noticed that the spherical efficiency of both arc lamps is better than that of the Nernst. In the lower hemisphere, the Nernst is somewhat better than the alternating current arc and not as efficient as the direct current arc. When reflecting shades are used, the alternating current arc again has a slight advantage for the whole of the lower hemisphere; but if we disregard the mean of the lower hemisphere and consider the floor or desk illuminating power of the lamp, we find that the Nernst lamp has a very decided advantage over the enclosed alternating current arc; for example, if we consider the mean of the lowest 30° zone, the efficiency of the enclosed alternating current arc is 1.56 watts against one watt for the Nernst and the mean of the lowest 60° zone is for the enclosed alternating current arc, 1.45 watts against 1.23 watts for the Nernst.

Comparisons between the illuminating powers of the Nernst and incandescent lamps indicate a watt consumption in the Nernst lamp a little less than half of that in the incandescent for equal illumination. The superior quality of the Nernst lamp is also very marked both for reading purposes and for the correct determination of color.

A similar comparison between the illuminating power of the Nernst and enclosed alternating current arc lamps shows for an equal consumption of watts in the two lamps, a much superior

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floor illumination for the Nernst lamp. Although the measurement shows a slightly better general illumination for the arc lamp, yet the quality and steadiness of the Nernst light, together with the entire absence of shadow, give an impression of decided superiority in favor of the Nernst.

The two sets of curves, Figs. 8 and 9, show interesting com-

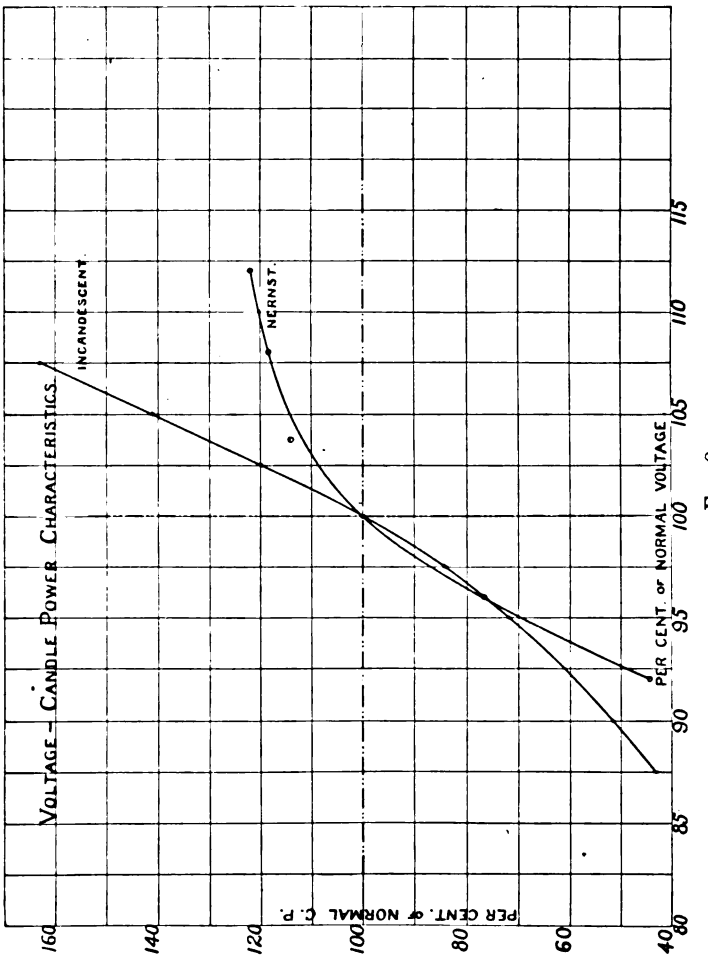

FIG. 8.

parisons between the Nernst and incandescent lamps under conditions of varying voltage. Fig. 8 shows the relative change in candle power and Fig. 9 the relative change in efficiency, all the variations in each case being given in per cent. of normal conditions. These curves are self-explanatory except as to the remark-

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able steadiness of candle power in the Nernst lamp when forced above normal voltage. The feature is due to the great corrective power of the iron ballast.

At present our data regarding the effect of running Nernst lamps at different efficiencies is rather limited. Figures of this character require many readings under all kinds of conditions and it may be some time before these can be satisfactorily and definitely recorded, but roughly, it may be stated that the efficiency of the glowers falls but slightly during their natural life, provided the lamps are kept properly cleaned.

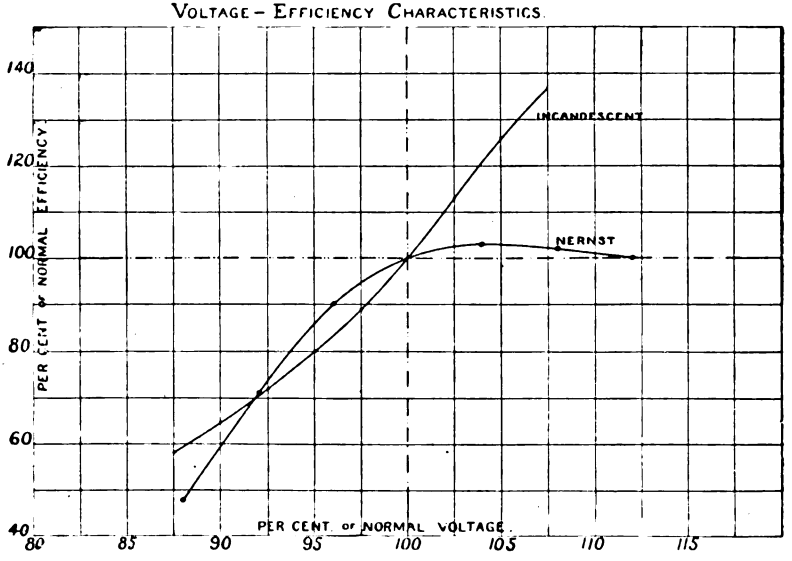

FIG. 9.

PERFORMANCE OF THE LAMP.

At the present writing, July 15th, there are in operation at East Pittsburg, 73 six-glower lamps, one three-glower and three single glower; in our laboratory and shop at Allegheny, 40 six-glower, 10 three-glower, and 21 single glower lamps; in the courtyard we have four outdoor six-glower lamps and in the tumbling room of the foundry, one outdoor six-glower lamp, all running on alternating current at 220 volts. In addition to these, there are 14 single glower direct current 110-volt lamps in Mr. Westinghouse's residence, making a total of something like 50,000 candle

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power in and about Pittsburg. At the Pan-American Exposition, we have lighted the interior of the dome of the Electricity Building by festooning 92 six-glower lamps from a pendant chandelier consisting of a central lamp of 30 glowers and 2,000 candle power encircled with six lamps of the six-glower type; on the floor, variously distributed, there are 12 six-glower, 24 three-glower and eight one-glower lamps. These figures are intended to give some idea of the scale on which the Nernst lamp has been developed and the resources which have been placed at our disposal.

Seventeen six-glower lamps have been running at East Pittsburg for more than a year, and are now showing an average life of 800 hours per glower. A similar record has been made with 14 six-glower lamps operating in Allegheny for about a year and a half. The four outdoor six-glower lamps have been running every night during the last twelve months through all kinds of weather, and up to the present time have not given a moment's trouble. The six-glower lamp in the tumbling room of the foundry failed in the cut-out at the end of 1,000 hours owing to the accumulation of a bunch of iron dust on the pole of the cut-out magnet, but a few strokes of a brush removed the difficulty and the lamp was continued in service.

The line service to these lamps has been fairly good for a shop circuit. As a matter of record, however, it was decided to test four six-glower lamps on a circuit having wide voltage fluctuations and to keep a record of the service and the lamp performance. The record follows:

Four six-glower, 220-volt lamps were run 1,000 hours. The run was continuous with the exception of three periods per day of one-half hour each when the lamps were turned off. A record of the voltage was kept with a Bristol recording voltmeter. An inspection of the voltmeter cards show that these may be classified under three types. Of the first, there were 15 cards, indicating that the voltage did not rise higher than 229 volts and only remained there for a short period. Of the second type, there were 26 cards, in which the voltage reached a maximum of 232 volts, maintaining this for about four hours. Of the third type, there were four cards showing a rise of voltage to 237 and remaining at 235 for five hours. These cards show that the lamps have been tested on a circuit, pressure of which varies from 4% below to 7½%

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above normal. There were no ballasts or heaters burned out during this run, nor did the lamps receive any attention or give any trouble.

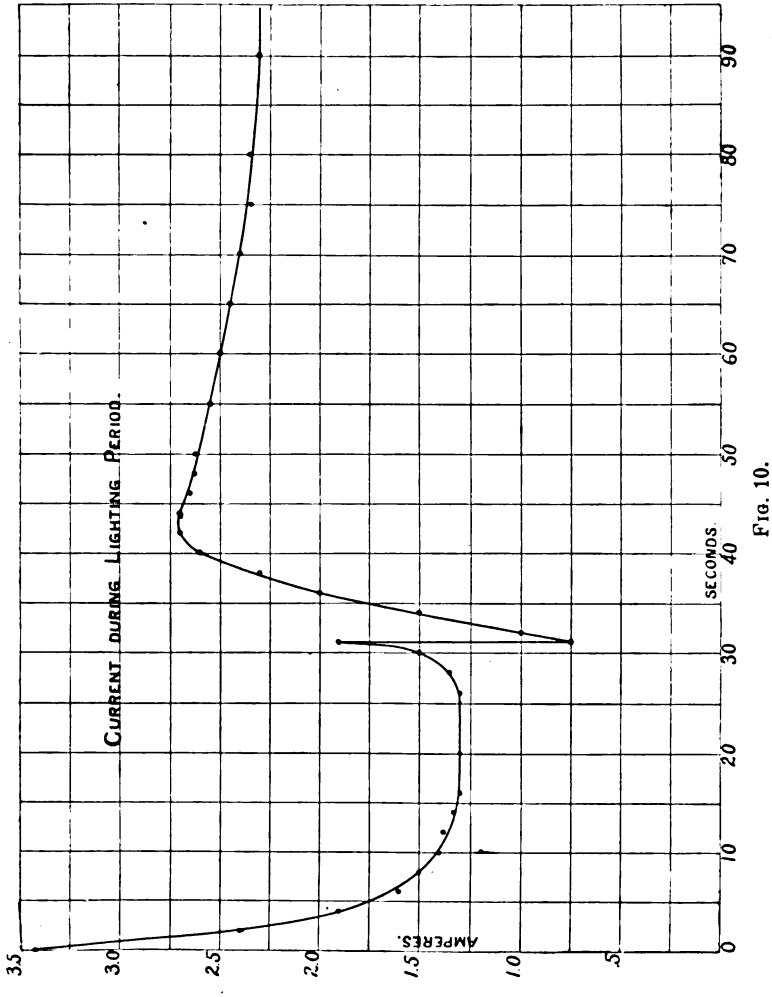

FIG. 10.

Of the 24 glowers in these lamps,

15 ran 1,000 hours;
6 ran 792 hours;
1 ran 580 hours;
2 ran 380 hours;

making an average of 890 hours.

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The three, two and one-glower 220-volt, alternating current lamps have given equally satisfactory service, but the glowers in the 110-volt alternating current lamp are not quite so uniform in their performance and the same glowers on direct current are comparatively short lived, averaging in the neighborhood of 150 hours; 220-volt glowers, however, on a direct current circuit would

FIG. 11.—Heater tubes and glowers.

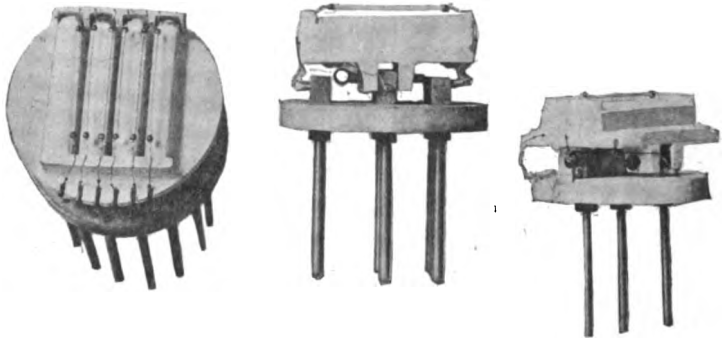

FIG. 12.—Holders for the six, two and three, and one glower lamps, showing an aluminium plug ready to be inserted.

last nearly double that time. At East Pittsburg, where a section of the Westinghouse works, about 350 feet long is lighted with 50 six-glower lamps suspended immediately above the traveling cranes, the features which strike me more forcibly than anything else are the beauty of the illumination and the total absence of shadow and flicker so intimately associated with the electric arc illumination in places of this character.

In connection with this topic, it will be interesting to note just what is going on in the lamp during the time of lighting, also during service under varying conditions of line voltage. Refer-

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ring to Fig. 10, we have a curve showing the current taken by a six-glower 220-volt lamp during the lighting period. It will be noticed that as the current is turned on, there is a sudden rush of nearly 3.5 amperes through the heater, which, owing to the temperature correction of the platinum wire, is quickly reduced to about 1.3 amperes. At the end of 26 seconds, the first glower begins to light; at the end of 30 seconds, the second glower is lighted and the heater is cut out, the current dropping at once to .75 of an ampere; the remaining glowers then light rapidly until at the end of 40 seconds all the glowers are lighted. From this point on, there is a slight drop in the current until the lamp reaches its normal running temperature.

Referring once more to Fig. 5, we find the current and voltage characteristics of the different elements in the lamp, and above these the characteristics of the lamp itself, the latter being the

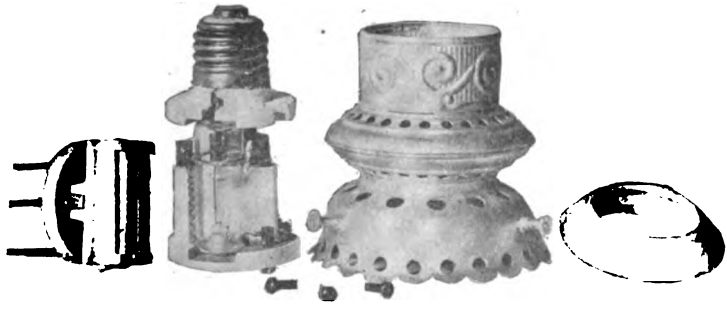

FIG. 13.—Parts of the single glower lamp.

sum of the cut-out coil, the ballast and the glower. The lamp curve was taken from actual measurements and approximates very closely to the sum of the elements, the slight difference probably being due to some differences of temperature. The voltage scale for the cut-out and ballast curves will be found on the right hand side of the diagram; that of the glower and lamp on the left hand side. Your attention is now directed to the excellent characteristic of this lamp, and when we consider the severe conditions imposed by the glower characteristic, I think we are to be congratulated on the results which have been attained. With a normal in the lamp of 2.4 amperes and 220 volts, it will be noticed that an increase of 14% in voltage causes but a 10% increase in current, resulting in a comparatively steady light

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and safe running conditions for the lamp in commercial service. A rise of 25% in the line voltage would burn out the ballasts in a very short time, but a rise of 10% for short periods does not seriously affect the life of either glower or ballast; a rise of 5% may be considered allowable for indefinite periods.

Repair and Maintenance.

When the lamps are first started, they require no attention. After 1,000 hours, however, the renewals become fairly regular and our experience shows an average life of 800 hours for the glowers, 2,000 to 3,000 hours for the heaters and an indefinitely long life for the ballasts. It will, however, be some time before

Fig. 14.—Two and three glower lamp, indoor type.

Fig. 15.—Six glower lamp, indoor type.

the average life of the heaters and ballasts can be definitely determined. The attention which these lamps receive, consists in having the inspector examine the lamps once a week through a colored glass to determine whether or not all six glowers are burning. If two glowers are out, the lamp is turned off, the holder removed and two new glowers inserted; the holder is then returned to its place and the lamp continued in service. Aside from such renewals, these lamps have not given the least trouble.

On the occasion of starting up 50 six-glower lamps at East Pittsburg, one of the engineers who had had considerable ex-

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perience with arc lamps, remarked that my troubles would now begin; but, frankly, I think he was mistaken. Aside from the renewal of the perishable parts, I see nothing in the lamp which could possibly cause trouble except under the most extraordinary circumstances. In fact, should a lamp receiving proper attention fail to light, I would look for the trouble elsewhere than in the lamp.

In commercial service it is intended that the central station shall make the renewals in the holders. The customer will be

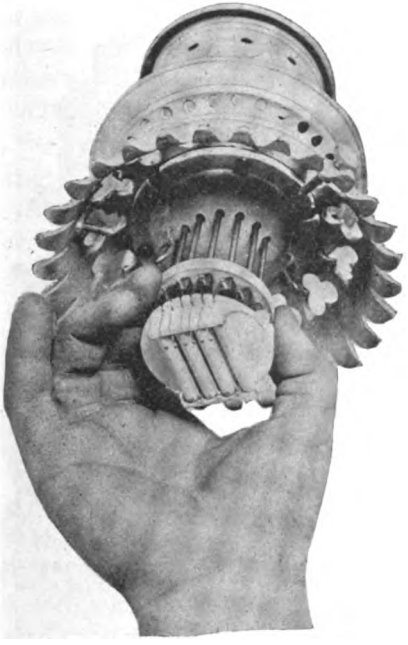

FIG. 16.—How to grip the holder without disturbing the glowers.

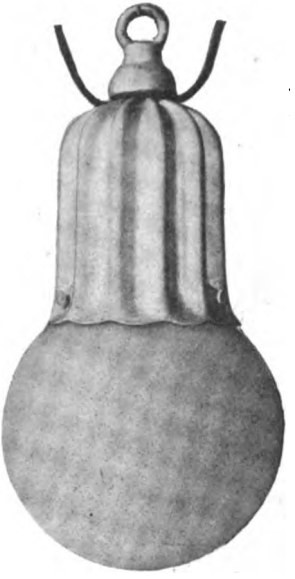

FIG. 17.—Six-glower lamp, outdoor type.

provided with a case containing a suitable number of complete holders, ready for service, so that when a renewal is to be made, the customer will simply remove the old holder and insert a new one, such operation consuming but a moment's time; then, at convenient periods, the old holders will be exchanged for new. Where lamps are used in quantity, the renewals will probably be made by the local attendant. The replacing of a ballast requires the removal of the lamp from the circuit, but after that the renewal is easily and quickly made. A slight withdrawal of one

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screw releases the ballast tube from its socket, whereupon the small aluminium terminal plugs may be withdrawn and the new ballast inserted. This operation does not require any tools other than a pair of small tweezers, and the renewal can be made without returning the lamp to the workbench.

After about 100 lamp hours, the heater case becomes somewhat discolored, and, for first-class maintenance, this should be cleaned at the end of that time. The following instructions for the care and inspection of the Nernst lamps are observed at East Pittsburg:

FIG. 18.—Thirty-glower lamp, indoor type.

FIG. 19.—Single glower lamp, indoor type.

Inspection of the Lamps.—The lamps should be inspected every 100 lamp hours. After being turned off, the lamp is turned on, and it is noted whether all the heater tubes become bright. If any of the heater tubes are burned out, the holder is replaced by a new one.

If the heaters are intact, the number of glowers burning is determined. If five or six are burning, the lamp needs no attention.

If less than five glowers are burning, the lamp is to be turned off, the holder taken out and the number of broken glowers determined by inspection. If the number of broken glowers is less than the number of glowers that were out, one or more ballasts

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are out of order and the lamp is to be taken down at once and the defective ballast replaced. When two or more glowers are burned out, the holder is to be replaced by a reserve holder.

Ballasts.—These are supplied in boxes marked "Ballasts for six-glower lamps," "Ballasts for one-glower lamps," etc. Burned out ballasts are to be renewed as soon as discovered and may be replaced without taking the lamp to the workbench.

Heater-Case.—This receives a coating of platinum black on the inside and should be replaced every 100 lamp hours by a clean heater case. The coating may be removed from the old heater case with a bristle brush running at a hight rate of speed. The heater case may then be used over again.

Glowers.—These are supplied in glass tubes marked with the voltage of the lamp for which the glower is intended, thus, "Glowers for 220-volt, six-glower lamps." Glowers marked for six-glower, are not to be used in a three or one-glower lamp and vice versa.

Heaters.—These are wound for 110 volts and are so marked. They are connected two in series for 220 volts. In the six-glower lamp there are four tubes connected in multiple series.

Heater Porcelain.—(This is the porcelain disk immediately behind the heater.) The heater porcelain is given a white coating which becomes fairly hard, but can be easily scraped or brushed off when it becomes covered with platinum back. When a holder with a black heater porcelain is removed, the glowers should be taken out, the old coat brushed off, except directly under the heater tubes, and a new coat of "heater porcelain paste" applied. This paste is a white powder which is to be mixed with water and applied with a camel's hair brush After replacing the heater porcelain and allowing it to dry in the air, run the heater for two minutes on 220 volts, placing the holder in a heater case. This hardens the coating, after which the glowers may be replaced.

Cost.—It is too early to say anything definite about the cost of these lamps. Fourteen or fifteen dollars would seem to be a fair price for a six-glower lamp, other lamps in about the proportion of the number of glowers. It is estimated that the cost of renewals will be considerably less than for enclosed arc lamps. Provision will be made for the return of the perishable parts containing platinum.

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Conclusion.

In closing, let me say that the Nernst lamp can in no sense be considered an experimental device. The development of details connected therewith has continued until all question of doubt as to its commercial success has been removed by the operation of a large number of lamps of various sizes and finished pattern for extended periods under commercial conditions, and it is confidently felt that the splendid exhibit of these lamps which may be seen at the Pan-American Exposition will prove a fitting demonstration of the complete and thorough manner in which the brilliant discovery of Dr. Nernst has been taken up and pushed forward in America.

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Discussion.

[In connection with his paper, Mr. Wurts exhibited and described a sample of the six-glower lamp, as typical of all the sizes made.]

Mr. Blodgett:—What would happen if you used the glower for the three-glower lamp in a six-glower lamp, or vice-versa? You said that they were not to be used except in the lamps for which they were marked.

Mr. Wurts:—A glower marked for six-glower lamp will run at a lower efficiency in a single glower lamp, the difference being due to the higher temperature and consequently lower resistance of a number of glowers running together as in the six-glower lamp.

Mr. Hering:—I would like to ask Mr. Wurts what happens to the heater when the glower breaks or gives out in a single glower lamp. It seems to me the solenoid will then drop its little arm, and that will put the heater into circuit; the current then flows continuously through the heater. Is any provision made for this case?

If in the six-glower lamp several of the glowers have burned out, is the magnet still strong enough to keep the others in circuit? I noticed that the currents for the six glowers pass in multiple around the magnet, and when several glowers break, the force of the magnet will evidently be weakened.

I also do not believe Mr. Wurts stated what proportion the ballast resistance was of the whole resistance in order to produce that excellent characteristic that has been shown. It would be interesting to know what the proportion is.

Mr. Wurts:—In the single glower lamp there is no provision for keeping the heater out of circuit when the glower burns out. The heater, however, has a comparatively long life, and it is assumed that in general a single glower lamp will be turned off when it is found that the glower is burned out. In many cases, of course, the lamp will not be turned off for several hours, but, owing to the long life of the heater, this is not thought to be a serious matter. In the multiple glower lamp the heater is kept out of circuit by the current passing through two glowers; thus, an ample factor of safety is provided against cutting in the heater except for the purpose of lighting the lamp.

When the multiple glower lamp is turned on, the heater is cut out as soon as two glowers have lighted, the remaining glowers then lighting from the first two. What was the other question?

Mr. Hering:—The other, I understand, is answered in the paper. I did not see it. It would be interesting to have Mr. Wurts tell us something about the nature of the conductivity of these glowers. As I understand it, the Nernst filaments have an electrolytic conductivity, but it seems that it cannot be entirely electrolytic, from the experiments published. Does he consider

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the conductivity to be partly electrolytic or entirely metallic? Is there any indication in the way in which the filaments finally break?

MR. WURTS:—I have not made a careful study of the electrolytic properties of the glower; the glower is generally understood to be an electrolyte. This is indicated by the action of direct current, and electrolytic action is absent on the alternating current. When a glower is about to break we find a rapid rise of potential, due probably to a crack in the glower, which soon breaks, forming a small arc for a moment until the circuit is ruptured.

Glowers that have been operated for six or eight hundred hours show a crystalline structure, and finally go to pieces. The exact process of disintegration is not clearly understood.

MR. J. W. HOWELL:—I think Mr. Wurts and his associates are very much to be congratulated on the work they have done. Each of the elements which enters into the construction of this lamp involves very considerable difficulties—the glower itself, with its connections, the heater and the ballast, and the three combined in one, constitute a piece of work the solution of which is very admirable. I wish to congratulate Mr. Wurts on it.

The characteristics of the glower, as shown in Fig. 1, are exceedingly interesting, and I do not think Mr. Wurts told us enough about them. If you study these curves you will see that any increase of voltage above the voltage of the top of that curve, which is about 197, will destroy the glower. Is that not right, Mr. Wurts?

MR. WURTS:—Yes.

MR. HOWELL:—So that the glower is designed to operate at a voltage, any slight increase of which will destroy it; this destruction is prevented by the ballast, and the very admirable way in which the ballast does it, as is shown on the curve a few pages subsequently, is a very pretty piece of work. In fact, the curve shows, that with an increase of voltage on the circuit there is actually a decrease of voltage on the glower. The lower curve, concerning which Mr. Wurts did not say anything, is to me very interesting—the action of the glower in vacuum. From that, it appears that taking the little circle which marks the point 1.76 watts per candle, that it occurs at a greater current, a lower voltage and a lower candle power. Now, if it occurs at a lower candle power it seems to me that it occurs at a lower temperature and that the glower itself will give better results in vacuum than it will in the air. If operated at a lower temperature its life ought to be longer, so that this feature, taken by itself, would indicate that you should burn it in a vacuum if it were not for the extraordinary amount of ballast which would be required on account of the shape of the curve. Now, am I wrong, Mr. Wurts, as to the temperature of the filament at the same efficiency in a vacuum? The candle power in air is 56; in

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vacuum, 46, for the same glower. Does not the decrease of 10 candles indicate a decrease in temperature with candle power?

MR. WURTS:—Yes, I should say that it did.

MR. HOWELL:—Well, if it is a decrease in temperature, then the filament ought to last longer in vacuum than in air, at the same efficiency.

I would like to ask Mr. Wurts if the blacking effect we see occurs in a vacuum.

MR. WURTS:—As I stated in my paper, we have not continued these tests further than to determine that there was nothing commercial in them. The question as to how the glowers would behave in a vacuum or in gases presented itself and it was thought desirable to exploit in these fields; but so soon as it was learned that commercial advantages were not to be found in this direction our attention was directed along other channels. As explained in the paper, the commercial efficiency was found to be low.

MR. HOWELL:—The ballast made it prohibitive?

MR. WURTS:—Not only ballast but the heater necessary to light the glower; also how would you propose pumping out the globe? We would have almost insurmountable difficulties. We succeeded, nevertheless, in making up a few lamps with a vacuum and with automatic heater, but it was rather a difficult thing to do, and the results which we obtained indicated that the commercial efficiency of the device would be small.

MR. HOWELL:—On page 553 there is a statement that Dr. Nernst brought with him from Europe some glowers which could be started by an alcohol lamp, or even with a match, but that the glower required in running these lamps takes 950 degrees centigrade to start it. I would like to ask Mr. Wurts what is the relation between the temperature at which the glower becomes a conductor and the temperature at which it fuses,—or the highest temperature in which it could operate. Those which could be ignited by the striking of a match must ignite at a lower temperature than 950 centigrade, I imagine.

MR. WURTS:—Well, the glower will light at a lower temperature than 950 degrees.

MR. HOWELL:—Well, it seems that some light at lower temperatures than others and become conductors at lower temperature than others. Now, is there any relation between the temperature at which they become conductors and the temperature at which they fuse?

MR. WURTS:—There isn't any that I have discovered yet. I don't know that I have particularly investigated that point.

MR. HOWELL:—When you take a piece of ordinary porcelain it will fuse at a comparatively low temperature compared with magnesium oxide, for instance. Isn't that right?

MR. WURTS:—Yes.

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MR. HOWELL:—And porcelain can be made a conductor at a very much lower temperature than magnesium oxide?

MR. WURTS:—Yes.

MR. HOWELL:—Now, is there any definite relation between the temperature at which they will become conductors and the temperature at which they will fuse?

MR. WURTS:—Well, there is a very decided relation there, but what it is or what kind of a curve it will produce, I do not know. Such material as glass, for instance, lights at a very low temperature, and if you take magnesium, or some substance like that, it will require a very high temperature, perhaps some substances will require an oxy-hydrogen flame to light them.

MR. HOWELL:—Those which require a very high temperature, such as the oxy-hydrogen flame, can't they be operated at a very much higher temperature than these substances which you are using?

MR. WURTS:—Yes, but they are very unstable. They will give you a horrible curve, and you have to put in such an amount of ballast that you can't get the commercial efficiency. Their point of efficiency is on that slope where you have the decreasing voltage with increasing current, and away down on that slope.

MR. HOWELL:—Then you cannot use in your lamps the substances which can be operated at the highest temperature?

MR. WURTS:—Why, they could be used.

MR. HOWELL:—I mean they cannot commercially?

MR. WURTS:—They cannot commercially.

MR HOWELL:—You are limited by the amount of ballast and by the temperature at starting?

MR. WURTS:—Yes.

MR. HOWELL:—About how much does the platinum cost in one of those six-glower lamps approximately?

MR. WURTS:—The platinum in the whole lamp?

MR. HOWELL:—The six-glower lamp.

MR. WURTS:—In the neighborhood of two cents, the platinum on each glower; and about 80 cents in the heater.

MR. HOWELL:—In the whole heater?

MR. WURTS:—Yes.

MR. HOWELL:—Ninety-two cents, about.

MR. WURTS:—Yes.

MR. HOWELL:—The development of the Nernst lamp abroad seems to have followed slightly different lines from what it has here. I have a letter from a friend of mine who has returned from Europe recently, and who states that in Berlin they are using Nernst lamps which give 25 candle power in a downward direction and 18 at the side, which consume 40 watts, and that there are 50,000 of them in use in Berlin, and yet I understand that your lowest candle power lamp is about 50. He also states that those lamps sell for a dollar, and are replaced for 25 cents. I just give you this as a piece of information.

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I would like to ask on what data Mr. Wurts bases the statement, on page 559, that the Nernst lamp has a watt consumption a little less than half the incandescent lamp, for equal illumination.

MR. WURTS:—I base that statement on some measurements that were made with the Nernst lamp and incandescent lamps. That is, lighting measurements, floor and wall illumination. These measurements had been made by an incandescent lamp man. I took his result, and that was the general conclusion reached by those present.

MR. HOWELL:—I do not think, Mr. Wurts, that the table you show above bears that statement out.

MR. WURTS:—The table refers, you know, to arc lamps.

MR. HOWELL:—Well, the six-glower lamp—you gave the figures there for six-glower lamps, and I can give you all you want on incandescent lamps. The illumination of two lamps can only be compared by the spherical illumination, or else by their illumination under exactly similar conditions. If you want to compare the downward illumination of two lamps you must place them in the same conditions, with reflectors placed above; but if you eliminate the reflectors, you cannot compare the light of the lamp in any direction, and the spherical candle power is the only correct comparison that you can make. In the table here the spherical illumination of the six-glower lamp is about $3\frac{1}{2}$ watts per candle, and that is not American candles, either. It is European candles.

MR. WURTS:—They are all reduced to the same.

MR. HOWELL:—Well, there are no incandescent figures here, though. I am talking about the incandescent lamp. In order to compare the Nernst lamp with the incandescent lamp, there is one element which is absolutely necessary, and that is the life and candle power curve in the lamp. If you base the statement on initial ratings only, it is impossible to form any comparison, because you can make the incandescent lamp efficiency anything you like, down to $\frac{1}{2}$ watt per candle. So that the bare statement of efficiencies is of no value whatever in comparing two lamps. Now, there is no statement in the paper as to the life and candle power curve of these lamps, but if you take the initial spherical candle power as $3\frac{1}{2}$ Hefner units, the ordinary 3.1 watt incandescent lamp has a spherical efficiency of 3.28 Hefner units, which is a lower figure than the other, and the ordinary $3\frac{1}{2}$ watt lamp has a spherical efficiency during its useful life, which is about 800 hours, of 4 watts per spherical candle—

MR. WURTS:—Three and a half, 800 hours.

MR. HOWELL:—Hefner units; that is, not American units. Now, I think the comparison made by Mr. Wurts is not a fair one, as to the spherical candle-power, due to the fact that there is no life or candle-power curve of the Nernst lamp given. I

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think it ought to be modified. In fact, if this glower indicates the condition in which it is after 100 hours' use, the blackening would indicate a considerable loss in candle power, and if it needs cleaning in 100 hours it would have to be taken out of its case and practically a new one put in. Of course, the expense would not be very great, but the useful life of the operative lamp is the time before it has to be renewed; and I think this lamp is ready for renewal now.

I would like to ask Mr. Wurts how a lamp on direct current breaks? He says it lasts only half as long as the regular one.

MR. WURTS:—It usually breaks at the terminal, where there is electrolytic action, and where this platinum black deposits in the pores. In regard to the question just before the last one, as to the statement on page 565, I cannot say that I have exactly reproduced the conditions of lowering voltage and having the voltage come on again. But we have frequently had the lamps go out; lamps that have been burning on commercial circuits, and had the current cease and immediately come on again as they were switched over in changing the dynamo. And we haven't yet had any instance in which fuses were blown or any trouble occurred.

You will notice in the curve on page 563 that the current which is on the heater, at 3½ amperes, is on the circuit for only a moment, and if the current is turned off the lamps and turned on again within, we will say, four seconds, the glowers will immediately light again.

MR. HOWELL:—It will hold its heat four seconds?

MR. WURTS:—Yes; and if the current is turned on again at the end of four seconds, the cut-out will instantly open and the glowers will again light from their own heat, and the action of the lamp under such circumstances would not affect the power house.

MR. HOWELL:—That would not; but if you had to wait thirty seconds it might.

MR. WURTS:—If you had to wait thirty seconds, the glowers would become practically cold and the lamp would simply light up from normal again, according to this curve.

MR. HOWELL:—But the heaters take a higher current.

MR. WURTS:—They take the current shown in this curve (indicating).

MR. HOWELL:—That isn't very much.

MR. WURTS:—For an instant of time the current taken by the heater when cold, is slightly in excess of the normal current of the lamp, but this is so quickly reduced, owing to the positive correction in the heater, as to make it a matter of no consequence whatever. We have never experienced any difficulty whatever from this source.

With reference to the lamps made in Germany, we have not yet made any attempt at smaller candle powers than 50. We

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purpose in the near future to have a 30 c. p. lamp, but in our judgment, anything smaller than this would involve such delicate apparatus in the interior of the lamp as to make it unfit for ordinary service. I may be mistaken, but so far, we have not thought it worth while to attempt anything lower than 30 c. p. The small lamps referred to, which are made abroad, have a comparatively small radiating surface and in a number of these which I have tested, I have found the temperature of the lamp sufficient to destroy, in a comparatively short time, some of the materials in the interior; for example, I found that the cut-out coils were provided with silk insulation and that the ends of the coil were made of fiber. After running about ten hours, these combustible materials were found to be black, entirely burned out, rendering the lamp useless for further service. There were other features in these small lamps which did not appeal to me as practical and which made me feel that these lamps were not commercial.

With regard to efficiency, I have begun my section on this topic by saying that it is not an easy matter to state the efficiency of the light, to the satisfaction of all concerned. I knew very well when I wrote this paper that these questions would come up and I do not think that they are settled yet by any means. "The proof of the pudding is in the eating," and we know from the comparisons that have been made that we have in the Nernst lamp a lamp which, for the same consumption of power, will give a better illumination and a superior quality of light, no matter what the measurements on the photometer may indicate. We know these facts to be absolutely correct, and these facts are what the customer wants to know; he wants an effective and efficient light. We have designed our six-glower lamp—a large unit—so as to throw all the light downward where light is ordinarily wanted, in factories, dry goods stores, railway yards, and places of that character. In such places, all the light is required on the ground, on the floor, or on the counter and not on the walls. Of course if it is desired to diffuse the light, this may be effectively done by the use of globes.

PRESIDENT STEINMETZ:—Gentlemen, I must say, before I give the floor to the next speaker, that in discussing the merits of an apparatus newly introduced, which is here brought to our notice for the first time, and which has been for years an entirely experimental apparatus and is now just being changed over into commercial form, at least so we hope, it is not fair to compare it with an apparatus established by experience, and successfully established, for many years, such as the incandescent lamp. We must expect in such a novel and recently developed apparatus that there will be a number of features which under certain circumstances may be objectionable, and which must be left for their development to practical experience in the use of the apparatus in commercial operation; as, for instance, this relatively

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large starting current, which in many cases would not be objectionable, but in other cases would be objectionable, as in the lighting of a whole system fitted with these lamps. As soon as found to be objectionable. I have no doubt whatever that means will be found to eliminate the difficulty, and so as to all other features which are perhaps not quite satisfactory yet under certain circumstances, and which our experience merely has to make satisfactory. So it is not quite fair to compare the Nernst lamp, which is an entirely new apparatus, just beginning to be introduced commercially, with the well established incandescent lamp.

Regarding these candle powers, I may say that a consumption of 3½ watts per candle for the Nernst lamp appears to be abnormally high, but if you go to the next column you get consumptions for the arc lamps of over three watts per candle. Now, that is very much higher than we are accustomed to consider arc light consumption, and I am led to believe that in measuring the efficiencies certain conditions existed different from those usually chosen, and that therefore these efficiencies do not compare directly with what we call efficiencies in incandescent lamps, of three watts per candle. Such an assumption would support the statement of Mr. Wurts, that the Nernst lamp has a much higher efficiency than the incandescent lamp, but if the above figures are taken, the Nernst lamp would come below the high economy incandescent lamp.

I would like to ask Mr. Wurts, with regard to this black deposit which forms on the glower in operation with direct current, whether he has determined the nature of it, whether it is platinum or whether it is electrolytic metal, and furthermore, whether he knows what is the approximate temperature of the filament or glower, in operation?

MR. WURTS:—I cannot say that I definitely know the nature of the black deposit on the glower. I think, however, it is platinum black. As to the temperature of the glower, I have really forgotten. We made some rough determination of about 2500° centigrade. It is rather difficult to get these temperatures accurately, but it was something in that neighborhood.

PRESIDENT STEINMETZ:—Was it determined by estimation from the light radiation or by calorimetric tests?

MR. WURTS:—Calorimetric tests. With reference to photometric measurements on the lamp, I would like to call your attention to the quality of the light. Possibly this would make some difference in a comparison made between Nernst and incandescent lamps. If you will look at the Nernst lamps in the Electricity Building and then look either way up or down through the main aisles, you will notice the light giving power of the Nernst lamps. What a glorious light it is that is thrown down on the floor! You will be impressed with the volume of light that seems to be emitted from each lamp. Then look at the

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light given by the arc lamps. They are bright spots to look at but they fail to illuminate the floor.

With regard to the blackening of the holder which Mr. Howell spoke about, it does not seem to me that this is anything like as serious as he would make it out. It is nothing like as serious in my judgment, as the blackening of the bulb of the incandescent lamp, for in one case you can clean it and in the other case you cannot. In a large majority of cases, incandescent lamps are run to death simply because the lamps continue to burn and give out some light, but they are then burning at a very poor efficiency, whereas with the Nernst lamp, a few strokes of a scraper will remove the black deposit on the holder and the efficiency is at once thereby renewed. Where these lamps are used in any quantity, it seems to me that the cleaning and care of them is a very insignificant matter.

MR. W. J. HAMMER:—Mr. President, I would like to supplement Mr. Howell's endorsement of the beautiful and efficient work that has been done by the Westinghouse engineers in this country in connection with the development of the Nernst lamp. I had the pleasure during the year past of spending more than five months in Europe and visiting practically all the places where work is going on with the Nernst lamp and seeing practically all the types that are being made in Europe. I also saw the American types of lamps abroad and in this country, and I was exceedingly impressed by the character of the work which was being done by the American engineers. The Nernst lamp is an illustration of that which we have seen before in the case of foreign inventions that have come to this country which have been made far more commercial and shipped back again to the foreigners. There are several points in the present type of Westinghouse-Nernst lamp that particularly appeal to me. One is Mr. Hanks's very interesting clamp, and the other the getting rid of the spiral heater as it is used abroad and the substitution of a very much improved form. The little wrinkle of the recess or indentation around the openings where the leading-in wires pass, so as to prevent the settling of platinum black around the connection, is a very good thing.

There are one or two things I would like to ask Mr. Wurts. I know at the time I was in Berlin there seemed to be considerable dissatisfaction with Mr. Potter's very beautiful iron steadying wire, or ballast, and I understood that there was considerable being done with platinum and special resistance wires as a form of ballast. I would like to know to what extent the iron steadying resistance or ballast which is here employed has been displaced by platinum or special resistance wire. I noted also in England that they had considerable difficulty due to the expansion of the glower body itself. I saw certain types of lamps, and have some of them in my possession, in which, instead of the glower being held rigidly, one end was fastened to a tiny platinum wire, which

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passed through a platinum wire loop or spiral of the supporting wire so that it could have a side play, and the end of the tiny wire attached to the glower was brought down and attached to the supporting wire below this loop, and I was informed that this had gotten rid of a very considerable percentage of breakages due to expansion of the glower. I note that this trouble is very nicely obviated in the present type of lamp, but I think it would be interesting for us to know to what extent that difficulty has been met with here. The Welsbach mantle is so closely related in certain characteristics to the Nernst lamp that there is another very interesting point I should like to bring up. I believe the Welsbach mantle falls off in its efficiency about 25 per cent. in the first 60 hours of burning. I would like to know if Mr. Wurts can tell me about what the falling off in efficiency would be in the standard Nernst glower, say in the first 100 hours. That is, of course, leaving out of consideration the use of any powdered substance which can be removed with the platinum black upon it. I merely wish to know what the depreciation is in the glower itself.

There have been a good many strong statements made as to what the Nernst lamp is going to do to the arc and incandescent lighting industries. You know what Mr. Swinburne and others have said upon the subject, as to the ultimate effect of the Nernst lamp upon the incandescent and the arc lamp, and I think it would be very interesting to us all if we could get an expression from Mr. Wurts as to just what relative position the Nernst lamp will hold as compared with the incandescent and the arc lamp.

Mr. Wurts makes the statement in his paper that the alternating current lamp has a life of about 800 hours. He does not say what the life of the direct current lamp would be, and I think it would be interesting if he would state about what the results of their tests are. Of course, that feature—the life of the lamp—probably would improve as time went on. As our president says, this is a brand new thing, but at the same time it is a very hearty, robust infant, and we would like to know, in the present condition of affairs, what the life is of a Nernst lamp on direct current, whether it exceeds, say, 300 hours.

There was a reference in Mr. Wurts's paper to the use of platinum as a heater, and its advantages, and in reference to its cost, and in that connection a gentleman in attendance upon this meeting (I do not know whether he is here in the audience or not) showed me a few days ago some samples of a metal which he claimed had all the characteristics of platinum, and that a substance had finally been found which would displace platinum. I tried to get some further particulars, but did not. That gentleman may be present in the audience and may be willing to say something on the subject. But he did say that while it could be made for much less than the cost of platinum it would probably

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be put on the market at perhaps 25 per cent. less than the cost of platinum. This was not given to me in confidence, and if the gentleman is present this morning I think it would be very interesting to hear from him on this subject.

In going about on the other side of the water I noticed a number of places where the torch lighting form of lamp had been replaced by the automatic type, and it is self-evident that the automatic type of lamp is the lamp that is best suited and best qualified to fill the bill. I would like to ask Mr. Wurts whether it is proposed by his company to put out any lamps of the torch lighting type or not?

Mr. Howell made some reference to the cost abroad. I think the cost is a little bit in excess of what he stated, but the rental, I think, is about 72 cents a year. I do not know whether the company will adopt the policy of outright sale entirely or whether they will do as the foreigners do, install the lamps at an annual rental of 72 to 75 cents.

One other point—I think Mr. Howell referred to it—in reference to the use of the Hefner standard, which had been used in this paper, it is stated, so as to enable a more ready comparison to be made with the foreign practice and with the public statements regarding the Nernst lamp. It would seem that a statement showing a comparison with the standards of light used in this country would perhaps be of equal if not greater interest to those who are interested in the application of the incandescent lamp.

PRESIDENT STEINMETZ:—Gentlemen, the time is getting rather late, so I must ask you to be brief as possible. At the same time the discussion is very interesting, and we do not want to curtail it, though we desire to have it as short as possible.

MR. WURTS:—In regard to the falling off of candle power in the glower irrespective of the discoloration of the globes and porcelain parts of the lamps, I would say the loss is slight, possibly 3% in 100 hours. This loss is small compared with the loss of candle power in the lamp when it is neglected.

With regard to the shrinkage of the glower we have provided against any trouble from that source by making the glower and the leads U-shaped so that if there is any expansion or contraction it can take place without any strain. Soldered connections are used abroad, and for that reason the glowers and heaters are not easily or quickly replaced. In the American lamp we have taken particular pains to make the perishable parts easily and quickly replaceable.

With regard to the life of the direct current glower, I may say that we have done very little work in this direction for the following reasons: When we started with our work on the Nernst lamp we were aware that our friends on the other side were working with direct current only, and that they were working with small candle powers and it did not seem worth while to

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parallel their work. We started out on lines of our own. We decided to attack the problem from the other extreme, to make large candle powers and to use alternating current. We have made a few direct current lamps. They are now in operation, but we have not succeeded in getting more than 300 hours out of the glowers. I am of the opinion, however, that we shall eventually get a longer life than this from the direct current glower. We have tests under way which indicate this, and we are hoping to get 500 hours but I do not look for anything much better than this.

If the gentleman Mr. Hammer spoke of is present, I would be pleased to hear from him regarding that metal. If he is not here I may say a word or two.—I have tested the metal referred to and have found that it is not serviceable for the purpose of our heater; the temperature in the lamp is too high. The results did not compare favorably with the results obtained from platinum. So far platinum wire makes the best all around heater.

With regard to a torch lamp, or match lamp, I would say that the Nernst lamp in this country is the personal property of Mr. Westinghouse; it is not owned or controlled in any way by the Westinghouse Electric & Manufacturing Co. I am not yet informed as to what Mr. Westinghouse's plans may be with regard to the company which he will no doubt form. He has already prepared a large factory for the manufacture of these lamps in Pittsburg, and we purpose moving into that factory in about two weeks. We shall prepare to turn out these lamps in large quantities and hope soon to be able to fill the large orders which have already been received from all parts of the country. I doubt very much whether Mr. Westinghouse will ever make a torch lamp; it would not be popular in this country. We want a good simple lamp which can be turned on and which can be substituted for an incandescent lamp.

Mr. Hammer, you asked some other questions with reference to arc and incandescent lamps.

MR. HAMMER.—As to the relative position, in your estimation, to be occupied by the Nernst lamp. You will remember that Mr. Swinburne said as to what the Nernst lamp would do to the incandescent industry, in his Society of Arts lecture of February 8th, 1899: "Once the Nernst lamp becomes so general that systems of distribution are laid out to suit it instead of the carbon lamp, the carbon lamp is practically 'out of the running'"; and Dr. Blathy told me in Budapesth last October, that when the Nernst lamp became a commercial article there would be no more arc lighting. Now, with your experience I thought it would be interesting to know what the relative position of this lamp would be, as compared with the arc and incandescent lamp.

MR. WURTS:—In my judgment, the Nernst lamp will be a sharp competitor of the arc lamp; not so much of the incan-

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descent. I think it will be largely used in dry-goods stores. One party said that the Nernst lamp would save them many thousand dollars a year owing to the fact that with incandescent illumination, ladies were unable to match materials, or if they attempted to do so, the purchase would be returned the next morning as unsatisfactory. I wish you would all examine the arrangement we have in the Electricity Building for showing this beautiful daylight quality of the Nernst light. Colored silks appear in their true shades and are matched as easily as by daylight. I think that the Nernst lamp will be largely used in factories, railway stations, railway yards and the like. One of the officers of the Pennsylvania Railroad Company the other day said: "You have no idea of the trouble we have in the yards from the shadows and flickering of the arc lamps. Locomotive drivers have difficulty in distinguishing switches and signals," but, he said, "that lamp is just what we want in the yards, a perfectly steady and shadowless light." I think that the beauty of this light as it appears in the Electricity Building will appeal strongly to all of you, and it is likely to be a competitor of any other illuminant where quality of light is a consideration. The fact that the single glower lamp requires twenty-five seconds to light, may prevent its being such a sharp competitor of the incandescent lamp as might otherwise be. Nevertheless, where incandescent lamps are grouped under a shade, I think the Nernst lamps will be found more desirable, more efficient, and lend themselves better to decorative illumination. For machine shop purposes, the absence of the shadow and flicker which accompanies the arc lamp, has made the six-glower type of Nernst lamp popular wherever it has been installed.

MR. OBERLIN SMITH:—How would it be for railway car lighting?

MR. WURTS:—You mean for street car service?

MR. SMITH:—No; steam cars, where electricity is used.

MR. WURTS:—It would make a very pretty light there. I don't know why they should not be used there as well as incandescent lamps. They would have the same advantages there as in a parlor or sitting-room.

MR. STILLWELL:—I should like to ask Mr. Wurts whether he has made any tests, such as he has spoken of, of the Nernst lamp on 25-cycle current. His test as I understand was made on 60 cycles. It occurs to me that if the Nernst lamp is entirely successful on 25 cycles, and I do not see any reason why it should not be, it has rather an interesting bearing on the general power transmission plants in the country. The only argument in favor of 60 cycles that has been given any very great weight recently, is that it enables you to operate arc lamps on the same circuits as are used for motors and incandescent lamps. If the Nernst lamp is applicable to 25 cycles it would be of very great value on these extremely long transmission systems that Dr. Perrine is interested in, in California, where a high frequency is objection-

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able for many reasons in connection with transmission, but yet where the desire to use arc lamps sometimes leads to the use of a frequency undesirably high.

MR. WURTS:—The lamp is operative on 25 cycles. As far as our tests with glowers go, we have not discovered any difference between 25 and 60 cycles. We cannot notice any flickering. The only difficulty we have encountered has been in the cut-out. The lamp before you was designed for 60 cycles, but when placed on 25 cycles—well, the cut-out does not hum exactly, it rattles. Thus we have a new problem to solve. We have now succeeded in designing a cut out which will operate on either number of cycles without noise or hum. You may hold your ear immediately beneath the dome shade and not hear a sound.

MR. HERING:—What is the frequency of your current here at the Exhibition?

MR. WURTS:—Sixty cycles.

MR. STERN:—I would like to ask Mr. Wurts one or two questions regarding the strength of the glower, when the lamp is under heat, as it might be effected by vibration. The question might come up in car-lighting, or in contemplating the use of these lamps for automobiles where considerable vibration is encountered in running over rough roads, and it occurred to me that while in a heated condition, the vibration might cause the rupture of a glower, thus shortening the lamp's life.

Another question is one as to its actinic power when used in photography. A lamp of this kind might be of considerable use in photographic printing, copying and the like, as a better means for getting a steadier light than the arc lamp, were its actinic power sufficiently high to permit of short exposures.

PRESIDENT STEINMETZ:—Are there any more questions to ask?

MR. ALEXANDER:—I would like to ask Mr. Wurts a question or two. As I understand it, the heaters of the lamps are cut out when two glowers are burning.

MR. WURTS:—In the six-glower lamp.

MR. ALEXANDER:—If that is the case, is it necessary to have four heaters? Would it not cheapen the lamp, lessen the blackening and cut down the high starting current of the lamp if less than four heaters were used? Inasmuch as two-glowers bring the other glowers up to conducivity, why would it not be necessary to have only sufficient heaters to bring up to conductivity two-glowers, and let them set the other glowers active?

MR. WURTS:—With regard to the strength of the glower when hot, I would say that the glower is by no means brittle at that temperature. If a glower is too long and heavy, it will sag, but if properly proportioned, it will remain almost perfectly straight. I do not think there is any danger of glowers breaking in car service, although I do not speak from experience.

I am not able to give any information regarding the photographic properties of the Nernst light. As yet, we have not

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made any investigations in this direction. I can imagine that the light might be useful in this sphere.

The reason we use four heater tubes to light two-glowers is this: Suppose that the two-glowers immediately underneath the two heater tubes were burned out, then the other glowers would not light. We must be able to start any two of the six-glowers and this requires four heater tubes. The principal idea, of course, in cutting out the heater when two-glowers are lighted is to save the heater from being cut in when three or four-glowers are burned out. With only two heater tubes, there would certainly be danger at times of not lighting the lamp.

MR. HOWELL:—I got a wrong impression from page 531, Mr. President, where I spoke of the normal current of a lamp as $\frac{3}{4}$ ampere, and starting current $3\frac{1}{2}$. That is a mistake. The normal current is not $\frac{3}{4}$, but 2.3 amperes. That .75 was for one glower, so that the short-circuit effect I spoke of would be nothing.

PRESIDENT STEINMETZ:—Gentlemen, we have had a very interesting paper and a very interesting discussion. I may draw your attention to one feature. If there are any further questions to ask they might be asked by communication and will be submitted to Mr. Wurts, and he can answer them by communication, so that if any question has been left unasked to-day you still have a chance to ask it and to get an answer.

[Adjourned to Saturday, Aug. 24.]

[COMMUNICATED AFTER ADJOURNMENT.]

PROF. A. J. ROWLAND:—As I listened to the discussion of Mr. Wurts' paper, I was impressed by the importance of the number of candles power given by a light source. In his paper, Mr. Wurts adheres pretty carefully to the lamps as being 1 glower, or 6 glower, and the like, only mentioning candle power when the efficiency of the light is considered. In the discussion, however, and at the Westinghouse Company's magnificent display in the Electricity Building, constant reference is made to their candle power, while commercially the lamps are rated as 50 c. p. and multiples of that (p. 555 of the paper). This figure is evidently the "end on" candle power. In the Nernst lamp, then, we have the one first to be *commercially* rated for candle power and efficiency upon the "end on" candle power, the importance of which is recognized by Mr. Wurts in his paper by designating it as desk illuminating power. Personally, I not only think this of the highest importance, but one of the things which will make Nernst lamps of the utmost value. I shall be greatly surprised if it does not have a most important bearing on the commercial rating of other artificial illuminants, especially those using the electric current, when the Nernst lamp comes into competition

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with them. This is not an argument for "end on" candle power as the important one; but a question, why in these lamps, which must compete with lamps of other types in present use, the glowers were not placed to give maximum candle power from the sides of the lamp, naturally suggests itself.

As I have thought of the Nernst lamp and its probable future, now that in the hands of Mr. Wurts and his assistants it has been prepared in such complete and careful way for American service, it has seemed to me that it must take a place which is filled neither by arc nor incandescent lamps. In fact, the Nernst lamp seems to be a sort of cross between the arc and the incandescent lamp, in which some of the faults of each are suppressed and the good features retained.

The incandescent lamp, as usually constructed, is very deficient in "end on" candle power; the arc lamp throws no light directly below it, except by diffusion through the globes. The Nernst, on the contrary, gives its maximum candle power in the "end on" direction, or directly below it. Even Mr. Howell, in his remarks, recognized the importance of desk illuminating power by noting the fact that the arc lamp fails by not sending its light below it.

The Nernst lamp somewhat suggests the enclosed arc lamp in the form in which Mr. Wurts has shown it, and has its merits, but it has others which the enclosed arc lamp lacks. The light is in the right place, the efficiency is high, the color of the light is very good, and the light is steady. I do not think that Mr. Wurts gives full credit to the real efficiency of the Nernst lamps as compared with arc lamps, for the latter have their candle power cut down so very much indeed by globes (put on for the sake of producing better light distribution or to suppress the purple color of the arc itself) that a *maximum* candle power of 200 from a 5-ampere 110-volt lamp is all that is procured.

The trimming of a Nernst lamp is not much different from the trimming of an arc lamp, but the ease with which the smaller sizes at least may be removed as one would remove an incandescent lamp, so that such repairs as would be impossible for an incandescent lamp may be done on them, is very noteworthy. By this method of construction the new lamps are adapted to interior work where lamps supplying light with poor color could only be used in the past.

I do not believe that the color of the light from the glower of a Nernst lamp can be considered equivalent to daylight, however. An ideal artificial light must have color like daylight as one of its requisites. So far as I am aware, no experiments have been made which show that the light from the Nernst lamps has this quality. Matching colors by incandescent lamps and then by Nernst lamps does not show it; even an analysis of the light into its spectrum determines little in this direction. The light from incandescent gas lamps (when a mantle of rare earths

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is used) is often called cold, ghastly and the like; and there appears to be an absence of the red rays, too plentifully present in nearly all artificial lights. I hope this fault is not one to be found when rare earths are used as a light source by being heated with the electric current, but cannot see how it can fail to be so.

One of the speakers in the discussion has asked questions regarding the depreciation of candle power with life in the Nernst lamp. In this connection I want to say that I am very confident that the depreciation in candle power of Welsbach mantle lights (which give the best example of the use of rare earths in lighting work) is immensely overstated. I fear that most figures one sees have been prepared by those who have most to fear from the competition of improved gas lighting. I speak with a knowledge of the most elaborate experiments which have been carried out on Welsbach mantles in this country, when I say that—burned as Welsbach mantles commonly are, at the highest candle power attainable with the gas volume and pressure available from a given burner—the average depreciation is not over 10 per cent. for the first hundred hours, quite a bit of which is due to shrinkage of the mantle to the shape of the unseen flame within. The life of a mantle is more than comparable with the life of the ordinary incandescent lamp. I do not believe the Nernst lamp has to fear failure from rapid depreciation in candle power. By suitably regulating the temperature of the glower and its efficiency, doubtless results quite as good as with incandescent lamps can be obtained.

With regard to the possibility of the Nernst lamp operating on 3,000 alternations, attention may be called to the fact that all the incandescent lighting of the Pan American Exposition is with alternating current at 3,000 alternations. It takes a very close observer to see any flicker, in spite of the fact that the candle power of the lamps is low and the filaments therefore very slender, so that their heating and cooling would readily follow the fluctuation of current through them.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 24th, 1901, President Steinmetz in the chair.

NOTES ON MODERN ELECTRIC RAILWAY PRACTICE.

BY ALBERT H. ARMSTRONG.

During the past few years electric traction work has been passing through a transition period, outgrowing the restricted limits of city surface traffic and encroaching upon a class of work hitherto accomplished with the steam locomotive. The broadening of the electric traction field has necessitated considerable development in the motive power, and the transmission and collection of electrical energy, and it is the purpose of this paper to briefly review some of the more important problems in electrical traction now in course of installation or under serious discussion.

The first case to be considered is the small city railway where 500-volt direct current generation and distribution amply suffices. As the system grows and the demand for suburban service increases, it becomes necessary to install either a large amount of feeder copper, a booster, or a storage battery. All of these expedients to take care of the suburban load are temporary, however, as they do not possess inherent qualifications sufficient to care for a rapidly growing system. There is a limit to the amount of feeder copper that can be economically installed; the booster if used continuously brings the coal consumption up to a prohibitive figure; and the storage battery is not adapted for an expanding system, and furthermore cannot successfully take care of long sustained overloads at the end of a suburban line fed from a city system.

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Transmitting energy by alternating current affords a means of feeding a large territory from a single generating station, but in the case of a small city road the amount of alternating current required is a small proportion of the total generating station capacity, the bulk of which calls for 500-volt direct current. The best method of meeting this demand for suburban service is therefore to install in the D. C. generating station a standard rotary converter operated from the D. C. bus bars as an inverted machine, and feeding a similar machine at the objective point by means of step-up and step-down transformers. The advantage of this method of generation is that both machines may be used as converters later on when the suburban load has increased sufficiently to warrant the installation of alternating current generators, replacing the direct current machines in the city station. Double current generators may be used, furnishing direct current for local consumption and alternating current for distribution purposes, but the installation of such machines presupposes that the ultimate load will be approximately evenly divided between the D. C. and A. C. output. It is probable, however, that the A. C. output will increase in a much faster ratio than the D. C. with its restricted area of distribution, so that double current machines do not afford the same convenience for taking care of future growth as do standard alternating current generators furnishing alternating current only.

The direct current system of generation, even for city distribution, becomes greatly handicapped with the continued growth of the city, owing to the large amount of power to be transmitted and the wide area which the city covers with its probably efficient street car service, thus relieving congestion in the center of the city. The alternating current generating station with substations scattered throughout the city appears to be the trend of the city distributing systems even where suburban connections do not exist, and where such suburban extensions do exist, all arguments point still more to the alternating current as the proper method of generating and distributing railway power.

One great advantage of the alternating current lies in its affording a means of consolidating adjacent roads under one system of generation and distribution; indeed, the alternating current is a prime factor in such consolidations, as it effects a large saving in operating expenses by doing away with the many

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small direct current stations required with the local 500 volt D. C. power-house.

The above discussion considers primarily the city surface road with suburban extensions running at moderate speed and operating cars of moderate weight, say, fifteen to eighteen tons. The growth of such a system in this country has been, first, the installation of D. C. operating apparatus, then the motor or engine driven booster, followed by the inverted rotary converter with alternating transmission, and finally, as the system expands, a large generating station containing high-tension alternating apparatus with several rotary converter substations suitably located to take care of the various parts of the system.

There is another class of railroads which differs in many points from the ordinary city lines, and included in this list are the elevated and underground rapid transit roads. The problem presented here is the operation of trains of two to six cars, weighing from 50 to 150 tons, at schedule speeds ranging from 13 to 16 miles per hour, with stops averaging from three down to two per mile. These roads operate on private right of way, stopping at designated stopping points, and are not influenced in any way by the surface traffic of the city streets.

The motive power to operate these trains at high schedule speeds and with frequent stops must be so designed that it can give an enormous torque during acceleration, and the controlling apparatus must provide for the efficient handling of these motors during fractional speed running. The problem becomes one of carefully determining the proper motor characteristics for efficient acceleration, and a proper motor design so that unsafe temperatures will not be reached from repeated temporary overloading of the motors.

Direct current has been generally used for such work, while the system of transmitting the electrical energy is in a transition period, but gradually changing over in the older installations and being installed in the newer installations as alternating current generation with rotary converter substations operating at 600-volts D. C. The reasons are the same as those influencing the change of the generating stations operating surface lines—the inability of a single direct current generating station to feed the large systems in operation with a reasonable amount of feeder copper, and the reduction in operating expenses resulting from replacing several D. C. stations with a single A. C. station well located.

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The D. C. series motor seems particularly well adapted for the propulsion of rapid transit trains running at variable speeds. Of the total input to the train, a properly designed motor equipment will give out over 70 per cent. as useful work at the car wheels—that is, all the losses occurring in the motors and in the controlling apparatus are less than 30 per cent. of the total energy input to the train. Where the runs are longer, and the train is permitted to run for some distance at full speed, the losses are of course considerably less; but even with the frequency of stops ruling in our elevated roads, the "efficiency of acceleration," so-called, is very high. This high efficiency of acceleration is due to the fact that direct current series motors can accomplish a considerable part of the acceleration of a train on the motor curve with starting resistances entirely cut out and motors operating with full line potential. This part of the acceleration curve may be made at an efficiency of over 85 per cent., thus making up for the starting resistance losses while the motors are running at fractional voltage. In making the above efficiencies of acceleration it is understood that the series parallel controller is used. A slightly better efficiency of acceleration is obtained by a series parallel controller provided for starting with four motors in series, changing to two in series, then all in multiple; but the complication of this controller is not warranted by the one or two per cent. higher efficiency obtained with it.

Elevated and rapid transit roads within the cities are built along the following lines: A single alternating current generating station well located with respect to cheap fuel and water, a transmission line consisting of underground triple lead-covered cables leading to substations suitably located with regard to the load, and operating at 600-volts D. C., a D. C. distribution system consisting of third rail and track return with feeders of either copper or rail, if required, and finally direct current series motors mounted either upon a locomotive or motor car, and controlled by a single controller or distributed throughout the train and controlled from a system of train control.

There is a new class of railways which is becoming the center of great attention. These are high speed interurban, or cross country lines of considerable extent. These lines operate on private right of way, are carefully graded, have few sharp curves and operate cars weighing from 30 to 40 tons at schedule speeds as high as 40 miles per hour, including stops at every three

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miles or more. These roads are paralleling the steam roads and make the same schedule speed as the steam roads provide, with the additional benefit of more frequent stops. Owing to the great tractive effort provided with motors connected to each axle, trains electrically driven can accelerate much faster and hence maintain the same schedule with more frequent stops than it is possible to accomplish with steam locomotives.

These interurban lines operate their cars through the city streets at the termini, thus picking up and discharging passengers at the most objective points and thereby making them still keener competitors of the steam railway systems. Owing to the high speed of these heavy suburban cars and the necessity for fairly rapid acceleration, each car or train unit will demand a considerable current when starting up. This current may reach 400 to 600 amperes per car, falling to 150 to 200 amperes per car when running at constant speed of 50 miles per hour, or more. Some interurban roads are being installed contemplating a maximum speed of nearly 70 miles per hour, so it is evident that the motors as well as the distributing system must be so designed that they can take care of enormous fluctuations in load. As these interurban systems are now being installed with 100 miles or more of track, the advantage of alternating current distribution at high potential is evident, and this method of distribution is universally used. Substations are located at intervals of ten to fifteen miles, and may or may not be equipped with storage battery auxiliaries. The storage battery effects a more uniform load curve on each individual substation, but the effect of such storage battery auxiliaries upon the generating station load curve may be quite small, due to the number of substations fed from a single generating station. A single alternating current generating station operating at 26,000 volts can feed the territory lying within 50 miles radius of the power-house, and the load thus secured, although violently fluctuating at the individual substations, is greatly smoothed out when the resultant load of the several substations is read upon the generating station bus bars.

In interurban work the direct current series motor shows itself to be capable of taking care of the widely different demands placed upon the motive power. For instance, the cars must be able to run for long distances at full speed with infrequent stops, but must also be capable of operating over city streets at city

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schedules with the stops six to ten per mile customary in city work. The series parallel control of motors is of course a considerable help, as it permits half speed running with motors in series, but even this half speed may be too high for city work, thus calling for considerable rheostatic control with motors in series.

Although great care is taken in laying out suburban roads to keep down the grades and eliminate the curves as far as possible, still the grades may be heavier than would be permissible with steam locomotive propulsion, owing to the greater traction provided with electrically propelled cars. The characteristic of the series motor which permits it to slow down on grades, and speed up on levels is therefore very valuable in this kind of service, as it reduces the fluctuations upon both the motive power and the distributing system.

The qualifications of the direct current series motor for interurban work have been entered into at some length, as there is another method of electrical distribution coming into notice—alternating generation and transmission, and alternating induction motors upon the cars. The system consists in brief of a multiphase generating station feeding into transmission wires extending along the line of travel, feeding at frequent intervals into step-down transformers which reduce the transmission potential to a still considerable pressure for the overhead trolleys. Induction motors receive their power directly from these trolleys and are geared to the car axles by the standard method.

A principal advantage of the induction motor system lies in the reduction of the labor account due to the elimination of attendance at the substations, the step-down transformers being self-cooled and requiring no more than casual inspection. Where the train service is infrequent and does not justify the expense of substation attendance every 12 or 15 miles, the induction motor system offers a substitute to the converter system worthy of very careful consideration. As the induction motor system introduces several features which are new, viewed from a direct current standpoint, a few of its characteristics will be touched upon.

The induction motor, while not a synchronous piece of apparatus, is such, so far as its behavior in railway work is concerned. A car equipped with such motors will run at practically constant speed up grade and down, or on level, thus making the

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car speed nearly independent of the profile of the road. The speed of the induction motor, depending upon the frequency of the source of supply, is not affected by the voltage, provided the voltage is sufficiently high to provide the torque required. This constant speed quality of the induction motor at first sight appears to be a desirable feature, as it would seem to ensure the maintenance of a constant schedule speed not influenced by grades. The greatest objection, however, is that the practically constant speed of the induction motor car up the severest grades calls for a very large motor output and produces much more violent fluctuations upon the distributing and generating system than is the case with the D. C. series motor, which falls off considerably in speed on heavy grades. The system, being alternating throughout, provides no means of introducing storage batteries to smooth over these excessive fluctuations, and they are more liable to reach the generating station and produce an irregular load curve with its greater coal consumption than is the case with direct current series motors and rotary converter substations, even though this may be used without storage battery auxiliaries. Where the system is so extensive that each individual car or train is a small increment of the total load, this objection of fluctuations upon the generating station will of course not hold true. The motive power, however, must provide for the running of the car or train up the steepest grade at practically the same speed at which the car operates upon a level, and the motors must therefore be designed to stand a greater output for the same service performed than the direct current series motor.

The induction motor can give only a certain maximum torque with a given impressed line voltage, and as this torque decreases with the square of the impressed voltage, it will be necesary to carefully determine the operating conditions of the motor and of the distributing system in order that the motor may be able to start its car or train upon the heaviest grade with the minimum line potential met with in operation. The direct current series motor can give a torque much in excess of any service demand, without sacrificing its running qualities at light loads. Railway service calls for a large overload capacity of its motive power, and the induction motor can meet these infrequent demands only by a design which sacrifices some of its advantages for normal operation. For example, a motor car to be successful must be able to operate through snow storms, occasionally haul a trailer,

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or push in a disabled motor car over the irregular profile of the road. An induction motor car designed to provide just sufficient torque to operate itself alone, would fail to give the commercial satisfaction which is given by the direct current series motor car with its capability of standing enormous overloads for a short time. It is evident that the practically synchronous operation and limited torque of induction motors introduce a number of problems into high speed interurban work not met with in direct current distribution, and that the motive power, transformer substations, distributing system and generating system must all be designed very liberally in order to take care of the violent and large fluctuations inherent in the operation of the railway induction motor.

The induction motor, like any piece of alternating apparatus, demands a magnetizing current, and this current is much larger than that met with in stationary motors, due to the larger air-gaps demanded in traction work. Stationary motors can run at air-gaps of but three or four thousandths of an inch, but the railway man would decline to assume the responsibility of keeping up his bearings for any such air-gap. Increasing the air-gap will raise the magnetizing current, lower the power factor of the system, and hence increase the size and cost of the distributing and generating apparatus. The necessity of designing the railway induction motor to meet unusual demands occurring very unfrequently further increases this magnetizing current, due to the high density required in the iron circuit with a reasonable motor weight. Even with a liberal air-gap, viewed from an induction motor standpoint, such a motor demands a clearance between field and armature nearly 50 per cent. less than is common practice with D. C. motors. The maintenance of linings with a small gap is a matter for consideration, particularly when it is remembered that when the armature of an induction motor strikes its field, it may destroy two sets of windings as the field is a duplication of the armature winding. We are therefore confronted with the maintenance of an air-gap of half the width and double the expense of repair with the induction motor to offset the small commutator maintenance of the D. C. motor.

The installation of high-speed interurban roads in this country has been brought about by the financial success of the earlier roads of this character. Because a system is operative is no reason for its adoption unless there is sufficient promise of its

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superiority over present methods. Our interurban and suburban roads possess a very strong advantage in being able to traverse city streets en route and at their termini. All the large cities in this country, and most of the smaller ones, have direct current railway systems in operation, and the direct current interurban and suburban system can therefore run its cars over existing city systems without in any way conflicting with the operation of such roads. The induction motor interurban system, on the other hand, would necessitate the changing of cars at the outskirts of the termini cities, running around the cities passed en route, or else the equipment of unused streets with double trolley and alternating current; or as an alternative, changing over the generating and distributing system and motive power of all cities entered, to alternating current. There are a number of engineering difficulties to overcome before such a change would be commercially practical.

A chief advantage of the induction motor system lies in the ability of running motors from trolley potentials far in excess of 600 volts universally used with direct current series motors. Not having any commutator, the induction motor can use trolley potentials of several thousand volts, and proper line insulation and safety in operating, are the only limits placed upon the trolley voltage. Owing to the large lagging currents demanded by induction motor roads which operate at power factors ranging from 50 to 75 per cent., it is desirable to use as high a potential as possible in order to eliminate the excessive feeder copper or frequent transformer substations required with low voltage distribution. A trolley potential, therefore, of 2,000 or 3,000 volts offers advantages in interurban distribution well worth the extra expense and development needed to insulate trolley and car wiring at this comparative high potential. In order that the motive power will be reasonably cheap, and bearing in mind that such motive power must stand maximum demands considerably in excess of the direct current motor, it is advisable to wind the motors directly for the trolley potential rather than introduce the expense and provide space for step-down transformers. We are therefore confronted with the difficulty of running a 3,000-volt trolley through small cities along the route and into large cities at the termini, even assuming that the cost of changing over such systems to alternating current would be justified.

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Step-down transformers installed upon the car, reducing from 3,000 to 600 volts, open the possibility of running motors without step-down transformers on city streets, and with step-down transformers when the trolley potential is 3,000 volts in the open country. The double trolley, however, complicates the city system and adds additional expense to the already expensive motor equipment. The induction motor, moreover, is not adapted to city street running, calling as it does for constant acceleration and efficient operation at fractional speeds. Instead of efficiencies of acceleration in the seventies obtained with direct-current motors, the induction motor would give an efficiency of only 40 to 45 per cent. during acceleration with a corresponding increase in coal consumption, making it compare very unfavorably with the direct current motor for city work. The adoption of the induction motor for interurban work seems limited, therefore, to those roads running on private right of way throughout, and having no connection with existing city systems at their termini or en route. Even in this class of roads, if the service is at all frequent and profile very irregular, the direct converter system with its third rail distribution may prove cheaper to install and operate. The reduction in operating expenses which the induction motor effects by dispensing with rotary converter sub-station attendants may be more than offset by introducing apparatus whose volt-ampere capacity may be double the K. W. capacity required, and which furthermore may operate with a very irregular and inefficient load curve as compared with the load curve produced with D. C. series motors.

The writer has endeavored above to bring out a few of the obstacles in the way of the success of the induction motor for general interurban work. There are, of course, special instances where the roadbed is practically level, grades and curves being eliminated and the conditions ideal for the installation of induction railway motors. It is unfortunate, however, that all interurban roads cannot pick out a level country, or have unlimited capital at the back of them in order to provide ideal conditions for the motive power. In fact, the motive power must accommodate itself to the physical limitations of the road, and it is just here that the direct current series motor shows its superiority to the induction motor where the profile is irregular and where the service consists of mixed city, suburban, and interurban high-speed work. As before stated, interurban high-speed roads are

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being rapidly extended in this country owing to their economic success, and in a large number of cases coming under the writer's observation, the induction motor could not compete in first cost of installation, nor in expense of operating with the D. C. motor, operated from rotary converter substations and high-tension alternating transmission. The expense of the few men required to operate substations is a very small item in the total operating expenses of the road, and as our interurban roads more nearly approach steam practice, they require attendants every 10 or 15 miles to serve as ticket agents, train dispatchers, etc., so that with a well-organized interurban system, the item of substation attendance can be largely charged to the general operation of the road and not to the cost of producing power.

The ideal conditions for the operation of induction railway motors seem to be a regular profile, either level or a uniform up-grade, private right of way with no city or suburban running, infrequent service, and freedom from unexpected and fluctuating demands upon the motive power. Electric railway work up to the present has demanded considerable of the motive power in the way of meeting large momentary overloads, running at different speed, line voltage, etc., and the direct current series motor has shown itself well equipped to meet these requirements. The induction motor is more adapted for operation under predetermined conditions, and its design does not lend itself to the same broad field of usefulness now covered by the direct current series motor.

In a service calling for frequent stopping where the demand upon the motors is largely acceleration work, the induction motor must dissipate considerably more energy for the same service performed than the direct current motor, and hence must be correspondingly heavier and more expensive. For constant speed running, the induction motor, however, must dissipate but little more energy than the D. C. motor, and from the nature of its design may dissipate that energy more rapidly.

This brings up a new class of railroad work just being considered, and that is mountain railroading, and long-distance cross-country roads for either high-speed passenger or freight work. The conditions governing both these classes of work are practically the same in that they demand a constant sustained output of the motive power, and it is in this class of work that the induction motor is being seriously considered.

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Direct current motors fed from a system of rotary converters connected to a high-potential transmission distribution system are open to the objection that a trolley or third rail potential under 1000 volts must be used, necessitating the collection of very large currents and an undesirable frequency of converter stations, or prohibitive expense of third rail and feeder construction. The power consumed by a freight train of 2000 tons or more may reach 3000 H. P. on the grades encountered in steam railway mountain work, and the ability of the induction motor to collect this large amount of energy at a trolley potential of 3000 volts or more, gives it a distinctive advantage in first cost of installation and expense of operation compared to direct current distribution. High potential alternating trolley systems present certain difficulties in the way of insulation, but after several years experience with high potential transmission lines, these difficulties should be easily surmounted. Such systems also employ locomotives and not individual motor cars, so that the high potential apparatus is localized, and more space is provided to properly insulate all high-tension wiring.

The operation of heavy freight trains, or high-speed passenger trains on trunk lines is the work of the future, and will be undertaken as soon as it is evident that a saving will result in operating expenses by the substitution of electricity for the steam locomotive. Trunk lines having local passenger traffic could very well equip their tracks with both high potential overhead trolley for the operation of heavy through trains and freight work, and also use a third rail construction to operate direct current 600-volt D. C. motors for the short haul work. Both these systems could be fed from the same generator and transmission lines, operating 25-cycle rotary converters to feed the third rail system at intervals, and step-down transformers to reduce the potential to the 3000 volts or more required for the overhead high-tension trolley line. This mixed system provides for the maintenance of a steady load on the generating station, while it permits the local and short haul traffic to benefit from the advantages of the D. C. motor for this class of work.

The electrical equipping of trunk line steam roads is a very large engineering proposition, involving such radical changes in the operation of such roads that its commercial success must be undoubted before the work is undertaken. It is possible that such a movement will be brought about by the equipping of

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some of the new high-speed third rail interurban systems with overhead trolley operating at 3000 volts alternating current. These systems are rapidly being extended and interconnected, and will soon be able to take care of long distance work when the systems are sufficiently joined together. The management of such roads, owing to their experience with electric traction, may be reasonably supposed to be more open to the advantages of electric haulage, while the establishment of a line of generating stations, all operating at the standard frequency of 25 cycles, will offer the means of feeding such a system with a comparatively small cost for equipping. The various substations, however, and the D. C. copper distribution are not adapted to the operation of large heavy units, although the transmission lines and generating stations could well feed these trains with a reasonable outlay for high-tension overhead trolley construction.

It is along such lines that the writer looks for the introduction of the induction motor as a railway factor in this country, and there are several propositions in view where the introduction of the induction motor seems justified and preferable to the steam locomotive now in operation.

Schenectady, N. Y., July 31, 1901.

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A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 24th, 1901, President Steinmetz in the chair.

ELECTRIC RAILWAY APPARATUS.

BY ERNST J. BERG.

With the extended application of electricity to heavy railroad work within the last few years, a number of interesting features have been brought out, the most important being what system to adopt and what apparatus to use in each particular case.

The object of this paper is to discuss the characteristics of the various apparatus, and, to a certain extent, their limitations, which, indeed, have almost entirely the deciding influence on the choice of system. The discussion of storage batteries is purposely omitted since their characteristics are well known and have been written up very fully within the last few years.

Continuous Current Generators.—By far the greater number of these are of the direct connected type. Their frequency varies from 6 to 15 or 18 cycles, and in some cases as high as 25 cycles. This latter frequency is adopted when, in addition to commutator, the generator is supplied with collector rings intended to take off more or less of the power as alternating current, that is, when the machines are "double current generators." With the exception of more extended use of direct connected units and double current generators, which are able to supply alternating as well as direct current power, very little if any radical modification in design or characteristics has been made during the last few years, but the progress has rather consisted in a steady and gradual improvement of design, especially in regard to sparkless commutator and overload capacity. Although the standard machines are over-compounded, in actual operation as a

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rule the direct current potential is kept constant at all loads, the over-compounding being used only to compensate for drop in speed with the load. When used as double current generator, the compounding on the direct current side is taken care of in the same way as when used as direct current machine, that is, by series winding, and the compounding for the alternating current load made by phase control, that is, the load, which usually is rotary converters, is made to take leading or lagging currents which react on the machine and thereby raise or lower the voltage as the demand may be. In order to accomplish this satisfactorily, the double current generators should have fairly high armature reaction, which means not too close regulation. This high armature reaction, usually less than standard direct current practice, is not objectionable from the direct current generator point of view since the regulation of potential is taken care of by the series field. Nevertheless it has been customary to ask for a regulation as close as 6 per cent. on the alternating current side, the intention being not to attempt any phase control, but permit the voltage to drop slightly with the load. Under these conditions obviously the closer the regulation, the better. The limit is reached when, due to the necessarily low armature reaction and the many armature circuits in multiple, the cross current caused by slight inequality in pole shape or gap becomes excessive.

Alternating Current Generators.—These are in almost every case directly connected to the steam engine and operated at a frequency of 25 cycles per second. If, however, a considerable portion of the power must be used for lighting, a higher frequency may be used. It must, however, be borne in mind that satisfactory parallel operation depends largely upon the frequency, and that the tendency to hunt, and in general, the difficulties of operating any installation satisfactorily, increase as the frequency increases. Twenty-five-cycles has the disadvantage that it is too low for in-door and for efficient out-door incandescent lighting, and entirely too low for arc lighting, therefore it is hardly advisable to use it for any kind of lighting, but when such has to be done, it is accomplished by rotary converters or motor-generator sets or frequency converters. Twenty-five-cycles has, however, so many advantages for railway work that it must be recommended, at least in all cases where induction motor-direct current generator sets are not advisable. The generators are usually designed for a regulation of about six to ten per cent.

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In view of the fact that usually a great many are operated in multiple in the same station, and therefore the load on individual feeders does not seriously affect one machine, it is preferable to go to rather high armature reaction since this limits the maximum flow of current and power in case of short-circuit, and suppresses large cross-current when operated in multiple from generators of not too close speed control. The European practice is to design these generators with polar windings for securing satisfactory parallel operation, but this has not been found necessary in America, where strict demands have been made upon the steam engine builders, who thereby not only proportion their machines with great care, but pay particular attention to the fly-wheel and governor construction. These generators are always of the revolving field type, and usually installed in connection with independent fly-wheel, whereas the practice in Europe is to make the armature of such a great fly-wheel capacity as to combine the fly-wheel and armature in one structure. One reason for the universal adoption of the fly-wheel type in Europe is that in most cases 50 cycles are used. With 50 or 60 cycles, and particularly with high-voltage machines, the diameter of the revolving field is, as a rule, enough to render it available as a fly-wheel, whereas with 25 cycles with relatively low peripheral speed, the cost of an unnecessarily heavy revolving field is often greater than that of an additional fly-wheel. Almost without exception they are designed for three-phase current and voltages ranging between 2000 and 13,000, depending upon the distance of transmission, etc. When used for voltages less than 6000, they have as a rule three slots per pole and phase, and for higher voltages two slots per pole and phase. The poles and the slots are shaped so as to give as nearly a sine wave as can be obtained by using machine-wound coils. (The use of machine-wound coils and entirely open slots is contrary to the European practice, at least until very recently, the practice being to use hand-wound coils in almost entirely closed slots).

Although smaller alternating current generators are made with automatic compounding, in no case is such compounding used with large direct-connected machines for railway work, but the control is done by hand, and the fields have only one winding.

Inverted Converters.—These are in their constants essentially direct current machines operating at 25 cycles, and are used to transform from direct current as obtained from the station

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bus bars to alternating current, which after being transformed to higher potential, is transmitted to sub-stations a considerable distance from the main station. The use of inverted converters is decidedly more efficient than the use of boosters, and is being introduced considerably. Although an inverted converter and a straight converter, that is, a machine transforming from alternating to direct current, to all appearances are identical, it is not always advisable to use one or the other indiscriminately. An inverted converter should preferably have lower armature reaction than a straight converter, and consequently is, as a rule, a larger and more expensive machine. The object of the lower armature reaction is to obtain closer speed control and to prevent as much as possible the tendency of the inverted converter to run away, in case suddenly an alternating current load of considerable magnitude or of very low power factor is thrown on. But even with inverted converters of such design it is not advisable to omit speed limiting devices, which may consist of a circuit breaker in the direct current leads in connection with a centrifugal device, or the inverted converter is excited by a special exciter directly connected or belted thereto. Indeed such exciter or "a compensated exciter" is very essential for the frequency control. The plain exciter may be shunt or compound wound whereby it is easily seen that as the rotary begins to speed up, the exciter also speeds up and its voltage rises, causing more current to flow through the shunt fields, which has a tendency to prevent acceleration. The compensated exciter, which is also a direct driven exciter, changes its voltages not only with the speed, but with the phase relation of current, increasing the voltage with lagging current going from the converter and lowering it when leading current is taken, which obviously is just what is wanted for close speed control. The ratio between the alternating current voltage and the direct current voltage depends upon the system, characteristics of the machine, etc., and is discussed later in connection with converters proper. It suffices here to state that it is a fraction, or in other words, the alternating current voltage is always less than the direct current voltage. It is therefore obvious that the alternating current delivered from an inverted converter is always of too low a potential to be used directly, and step-up transformers have to be used. In its potential control an inverted converter has not the feature of a direct converter of compound-

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ing for the load if required, but the voltage will drop with the load unless made up entirely of converters, which by taking leading or lagging current can react upon the inverted converter, but even with such load only a very low compounding can be obtained. Therefore, as a rule, the voltage of an inverted converter will drop with the load. In order to obtain constant potential at the receiving end of the system it is necessary that the converter proper should be compound wound and that reactances should be inserted in the leads so that the rise in voltage can be obtained across these reactances instead of at the inverted converter. Frequently inverted converters are operated in parallel with alternators on the alternating current side, and it is then as important to investigate the speed regulation of the prime mover driving the alternator as when contemplating running such alternators in multiple, since the inverted converter naturally runs at a uniform rate of rotation and therefore if the alternators to be run in parallel therewith are not run at a uniform rate of rotation, cross currents will be caused and serious difficulties might arise.

Rotary Converters.—Although converters of a higher frequency than 25 cycles occasionally are used, in most cases, and particularly when the plant is intended for railway work, 25 cycles are chosen and the discussion will therefore apply to them. Were it not that rotary converters some times cause trouble by hunting, there is hardly any doubt they would be used universally, even with the limitations in voltage control imposed by their use, instead of synchronous motor or induction motor direct current generator sets. The question of hunting, however, is so serious that frequently it is good policy to introduce the complication of running two or three machines instead of one, even at the lower efficiency, to ensure satisfactory service. Hunting is caused by many circumstances, one being that the rate of rotation of the prime mover is not uniform, another that converters are operated in the same network, but interlinked by lines of relatively high resistance, another that the converter has sluggish magnetic circuit so that it cannot quickly respond to variations in impressed voltage, still another that the impressed voltage on the converter, for some outside reason, tends to fluctuate suddenly. The remedy for the first case of hunting is obviously to get the rate of rotation of the prime mover more uniform, which often is very difficult, particularly if the ma-

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chines are already installed. (With the stipulations imposed upon the engine builders, this case of hunting is not now so serious and does not exist when the generators are driven by turbines.) Another remedy which occasionally gives satisfactory results is to use one or more induction motors of considerable size on the same circuit, or even a small induction motor with large fly-wheel, the tendency of the induction motor being essentially to steady the frequency by its momentum. The other cause, that of considerable resistance losses between converters or generators and converters, has a tendency to set up hunting also, since with a slight fluctuation in current, due to various causes, the voltages fluctuate also. This fluctuation in impressed voltage will react in the rotary converter, and if the magnetic circuit is not very sensitive, causes a state of unstable equilibrium which leads to hunting. It is obvious that if the E. M. F. supplied to the armature varies suddenly, the flux also must vary at the same rate to ensure the same relative position of the armature and the field. If the magnetism lags behind, the armature must take a different position from what it would have otherwise and thereby a pulsation in speed is set up and the rotary "hunts." It is therefore evident that the magnetic circuit should be as responsive as possible, in other words, all causes delaying change of magnetism should be eliminated. As a consequence it is not best to use magnetic material of low ohmic resistance, such as steel, but a considerable part of the magnetic circuit is made of cast iron which has high ohmic resistance, and damping devices are inserted not in the path of the main flux, that is in the poles, but midway between the poles. This damping device is only effective when the rotary hunts, that is, when there is an appreciable armature reaction which sets up currents to the circuit formed by the bridge. The last cases of hunting can be explained and remedied in much the same way as in the previous case, and sometimes preclude the use of converters in places where the rate of rotation might be uniform and where the ohmic losses between generators and converters might be small, the disturbing element being a fluctuating load placed near to the converter and therefore inducing periodic pulsations in voltage on the converter circuit.

Summarizing the hunting situation, we find that although there are a number of causes for this trouble, the phenomenon is fairly well understood and no great difficulties need be ex-

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pected in well planned 25-cycle systems. The other limitation of rotaries is the difficulty of obtaining wide range of voltage as compared with direct current generators, and providing for automatic compounding over a wide range.

Although it is possible to compound rotary converters to some extent by merely using a series field similar to that on direct current generators, the amount of compounding is very slight indeed and is obtained by leading or lagging currents taken by the converter and passing over the very low reactance of the converter armature proper. In order to compound to any considerable extent, it is necessary to have some reactance in the circuit between converter and generator, and to permit the converter to take wattless currents at almost all loads. The proportion of wattless current and reactance can be varied considerably, and still the same results obtained, so for instance, roughly speaking, 10 per cent. compounding can be obtained by 50 per cent. leading current and 20 per cent. of reactance; or by 20 per cent. leading current and 50 per cent. reactance, etc. The more reactance over a certain limit, the more liability of an unstable operation and the more wattless current, the poorer the power factor at light loads, and the greater the armature heating; indeed, with quarter-phase or six-phase converters the saving in armature copper is not great over that in three-phase converters, if too large a percentage of wattless current is used in phase control. A fair average is to insert about 15 per cent. reactance. With such reactance in a circuit of 6 per cent. resistance, it is possible to obtain constant potential at all loads with a power factor of 60 per cent. at $\frac{1}{4}$ load, 91.5 at $\frac{2}{4}$ load, 100 per cent. at full load, 99.5 at 50 per cent. overload, and 96.5 at double load, or even higher if the series field is so adjusted that the converter runs non-inductive at $\frac{3}{4}$ load, then a power factor of 73.5 at $\frac{1}{4}$ load, 97.5 at $\frac{1}{2}$ load, 100 per cent. at $\frac{3}{4}$ load, 99.5 at full load, 98 per cent. at 50 per cent. overload, and 96 per cent. at double load. Under these conditions the voltage not only is approximately constant over the whole range of loads, but is still within a fraction of 1 per cent. up to 50 per cent. overload.

With several rotary converters operated in the same station, it is advisable to use independent transformers, or at least independent secondaries for each transformer, since, if this is not the case, considerable cross-currents are likely to flow if the direct current brushes on each individual converter are not placed identically the same.

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The transformers themselves should preferably be designed with the greatest amount of self-induction, since, as stated above, in almost every converter installation some reactance is advisable. Thus the essential difference between a transformer used for lighting and a transformer used for converter is that transformers for rotary converters have more self-induction and higher efficiency than lighting transformers, or at least that in the design of these transformers this condition has been looked for.

The great advantage of rotary converters over motor-generator sets is the higher efficiency, due to the small copper and iron losses, and the facts that only one machine is used instead of two or more, that the power factor can be 100 per cent. at all loads, that they can act as condensers, and therefore compensate for lagging currents introduced by other apparatus on the system, that, in case of a very heavy load, they can give almost unlimited power, and that even as such shunt machines the voltage does not materially change with the load, but that it will at the most vary a few per cent. between no load and full load, whereas the direct current machine probably will vary perhaps 10 per cent. or more under the same conditions.

The ratio between alternating and direct current E.M.F. of a converter or inverted converter depends upon the system used, upon the ratio of maximum to square root of mean square value of impressed E.M.F. (that is, the E.M.F. given by the generating apparatus), upon the load of the machine, upon the ohmic losses in the machine, upon the position of the direct current brushes on the commutator, upon the excitation, upon the ratio of pole arc to pole pitch, and upon the operating conditions, that is, whether the machine is used to convert alternating to direct current power, or vice versa. Sixty cycle converters, which usually have shorter pole arc and higher commutator losses than 25-cycle converters, have, as a rule, higher ratios, and when used as inverted converters, lower ratios than 25-cycle machines.

At no load, with an average wave-shape such as given by standard generating apparatus, the average ratios are:

Percentage pole arc	67%	74%	80%
Three-phase and six-phase double delta: ...	62	61	60.5
Six-phase, diam. and two-phase.....	72.5	71.5	71

With the average losses at brushes and armature winding, this will give the following ratios at full load of a 550-volt converter:

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Percentage pole arc	67%	74%	80%
Three-phase and six-phase double delta. ...	63	62	61.5
Six-phase diam. and two-phase.....	73.5	72.5	72

INVERTED CONVERTER.

Percentage pole arc....	67%	74%	80%
Three-phase and six-phase, double delta.....	61	0	59.5
Six-phase, diam. and two-phase.....	71.5	70.5	70

The values apply when the direct current brushes are placed on the exact neutral point. If the brushes for some reason or other are placed either leading or trailing, these ratios are increased, that is, the direct current voltage for a given impressed alternating current voltage is less. This variation may amount to several per cent., therefore moving the brushes makes it possible to lower the direct current voltage, and thereby change the ratio to some extent without changing the transformer connections. It is, however, impossible to increase the direct current voltage, no matter in what position the direct current brushes are placed.

Changing the excitation will also change the ratio. With reduced excitation, that is, with lagging current, the ratio may increase a couple of per cent., and with over-excitation it may drop a couple of per cent. depending upon the electrical constants of the machine.

Synchronous Motor Driven Direct Current Generators.—These have the advantage over the rotary converters that they can be run on circuits of high voltage directly, without the use of step-down transformers, that the direct current voltage is independent of fluctuations in voltage on the alternating current side, and dependent only upon the speed control, and that by a mere change of field excitation the direct current voltage can be varied over a very wide range. Their limitation, however, is their tendency to hunt, which is quite as marked as with rotary converters. In other words, the limitations inherent to rotary converters exist also with synchronous motors and even to a greater extent, at least with synchronous motors wound for high voltages with relatively few slots, with which type it is decidedly more difficult to apply anti-hunting devices than with rotary converters, which, by their more distributed winding and large number of small slots, are less likely to have excessive eddy losses, in the anti-hunting devices. It is, therefore, questionable whether it is advisable to substitute such sets for converters under any con-

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ditions, the more so as frequently the cost of a synchronous motor wound for very high voltage is not much less than the step-down transformers and a low voltage motor.

Induction Motor Driven Direct Current Generators.—This combination has decided advantages over the first mentioned types by its stability, and may therefore find considerable field of application in systems of unstable frequency and fluctuating voltage, or installations which already have a number of synchronous apparatus. As stated regarding rotary converters, it is some times possible to obtain good results with hunting converters by installing induction motors of considerable inertia on the same circuit, and such a set naturally lends itself very well for this purpose. At moderate voltages, up to say, 2000 to 3000, induction motors can be built with good constants at a reasonable cost, and do not, therefore, involve the use of step-down transformers. At higher voltages, however, and particularly up around 10,000 volts, it is found that the use of step-down transformers not only introduces much better constants but frequently makes a cheaper installation. Under these conditions it is decidedly questionable whether it does not pay to install more line copper, remedy the speed control of the generators, or, in general, remove the causes prohibiting the use of rotary converters, since the cost of such motor generator sets is much higher, and the contents much lower, than when converters are used.

Direct Current Railway Motors.—The characteristics of this type of motor are so well known that it is not worth while to discuss them further than to say that in general the tendency seems to have been during the last few years to design the motors for a given train weight and maximum speed, disregarding the number of stops, provided the car is accelerated and retarded at a comfortable rate, which involves, of course, the schedule speed changing with the number of stops.

To accomplish this, the motors are so designed and particularly the ventilating conditions are such that the temperature of the fields will not rise more than a safe number of degrees if subjected to the accelerating current at the rate of say, ten times per mile, and the armature has such a low core loss that it can run for a considerable time at the maximum speed. Such condition is made possible with the modern mechanical design which readily conducts the heat from the inside to the outside, and thereby obviates great differences in temperature. The main

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difference in electrical design is that much more precaution has to be taken to have low self-induction in commutation. This is necessary since, as stated above, the field winding has to stand the full current of acceleration for a much longer time than formerly was the practice, and therefore a less number of turns and a weaker field in general is used in modern motors, this condition causing sparking unless the armature reaction is reduced and the number of commutator segments increased. We therefore find now as a rule a higher flux and a greater number of commutator segments than in older types of motors.

Alternating Current Railway Motors.—A very superficial study will show that whenever this type of motor has been adopted the reason lies, not with the motors themselves, but in the fact that a lesser amount of feeder copper and possibly fewer attendants are required with an alternating current railway system than with a direct current system involving rotary converters. It is, however, only in cases of relatively long runs with few stops, or in mountainous roads where power can be returned by induction motors, that economy can be shown with this system as compared with the direct current system. It is very doubtful whether in many cases where alternating motors have been installed, direct current motors would not have been better engineering.

The alternating current railway motors are of the polyphase induction type and therefore their characteristics are essentially those of direct current shunt motors, that is, they run efficiently only at one speed, whereas the direct current series motor will operate at high efficiency over a considerable range of speed. It is therefore obvious than in railway service where the speed for many reasons has to vary during the run and where cars are stopped and started at rather short intervals, the actual power taken by the induction motor will be greater than that taken by the direct current motor. Since, furthermore, any induction motor must take a certain amount of wattless current, the apparent power input of the motor must be greater than with direct current. With the same mechanical clearance in the two types of motors, the amount of wattless current taken by the induction motor would be quite prohibitive, therefore these must be made with decidedly smaller air-gap than direct current motors, which necessitates more careful adjustment, and involves more repair work. The wattless current is also dependent upon the

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voltage at which the motors are operated, and increases as the voltage increases. With the known methods of insulation and with the limited space available for railway motors, it seems that it is almost out of the question to consider a design at higher potential than 3,000 volts. Even with the smallest safe air-gap this will give a power factor of at the most 85 per cent. or 88 per cent. at full load under the best conditions, which with an efficiency of say 86 per cent. including gear loss, gives an apparent efficiency of at the most 77 per cent.; in other words, the K.V.A. input of the motor would be about 30 per cent. greater than that corresponding to the work done. Whereas with the direct current motor the power input would probably not be more than 12 per cent. or 15 per cent. greater than that corresponding to the work done. Therefore, and in view of the laws governing the design of such induction motors, it is to be expected that the copper losses in an alternating current motor will be decidedly greater than in a direct current motor. The core loss in the field of the induction motor is also greater than the core loss in the armature of the direct current motor at maximum speed, so that this gives another source of increased heating of the motor. This increased heating is decidedly objectionable, as it involves the use of a much larger machine than the direct current motor, which increases the cost and weight of the equipment. To illustrate this somewhat more concisely, consider the losses occurring in a couple of motors of direct and alternating current type while accelerating from standstill up to full speed. The core loss and eddy losses in the direct current motor are zero at standstill, and increase to a certain maximum at full speed. In the alternating current motor at standstill even under favorable conditions, the core loss in the field is the same as the maximum core loss in the armature of the direct current machine, and the core loss in the armature at standstill about the same as in the field. At full speed the core loss in the field still remains the same, but the core loss in the armature is zero and therefore, roughly speaking, the core loss of the direct current motor is in the neighborhood of half of the core loss at maximum speed, while accelerating, and is one and a half times as much in the alternating current motor. In other words, during acceleration the alternating current motors have three times as much core loss as the direct current. Adding to this loss the greater copper loss due to the larger power input of the motor, we find from

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actual calculations that the alternating current motors of good design will have in the neighborhood of four times as much loss as the direct current motors when operating over relatively short lines, as would be the case in rapid transit systems. To dissipate four times as much energy means that the volume of the motor has to be very much greater, and its heating facilities decidedly better. This does not mean that the actual heating will be as much

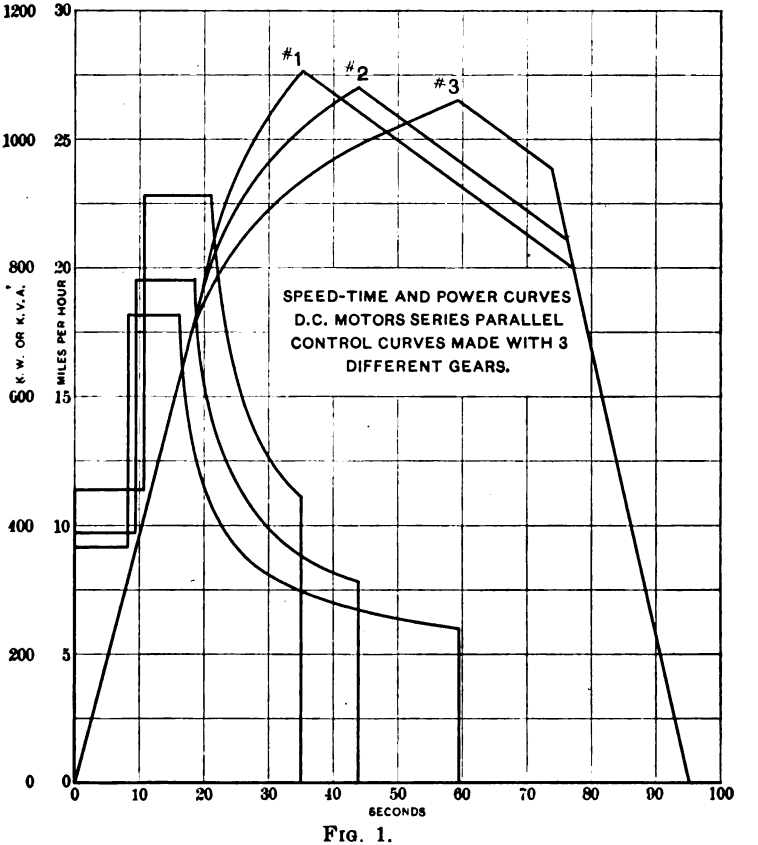

FIG. 1.

more, since at least in long distance runs, the time of accelerating is short compared with the total time of the run, nevertheless the loss will be decidedly more and consequently it would seem as if the actual cost of the induction motor equipment per car would be from 50 per cent. to double that of direct equipments, depending upon the service. Since the cost of the motor equipment is a very large factor in the installation of a plant, and

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since the direct current equipment is so standardized and brought down to the least possible cost here in the United States, this is

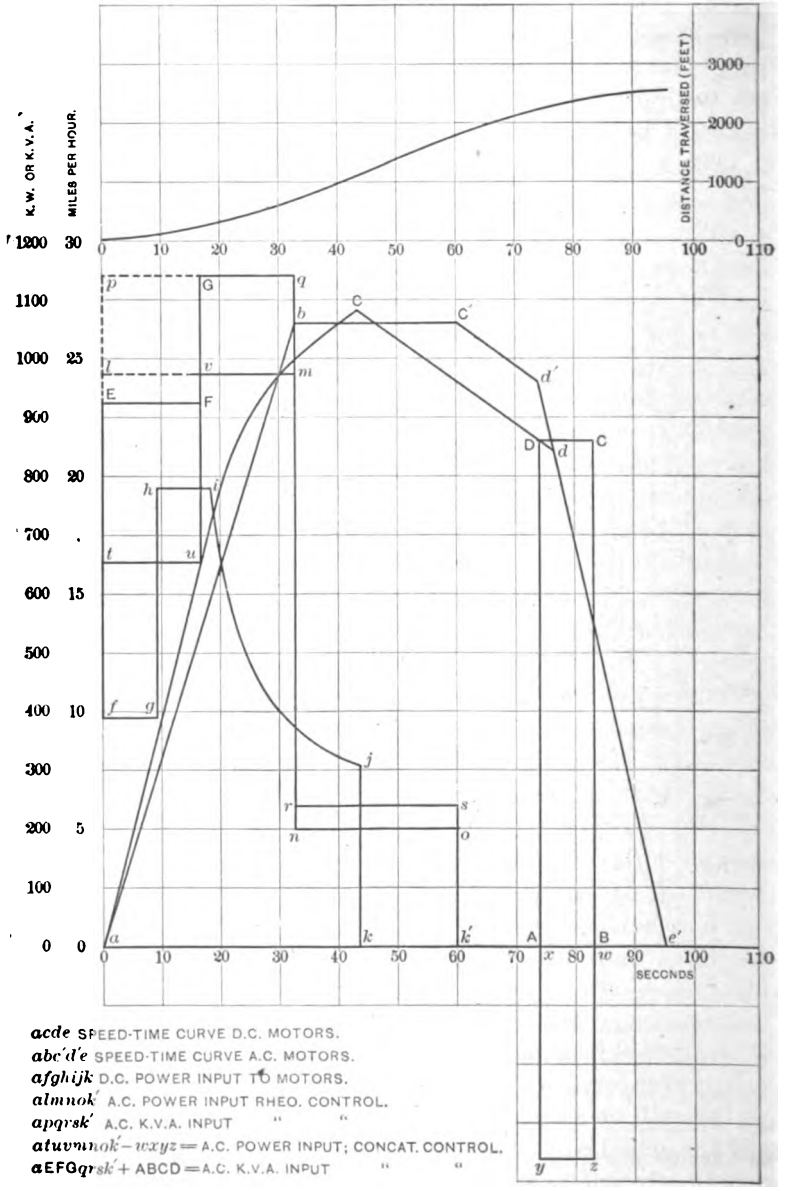

FIG. 2.

probably one of the main reasons why upon careful examination it has been found not only a saving of power, but great economy

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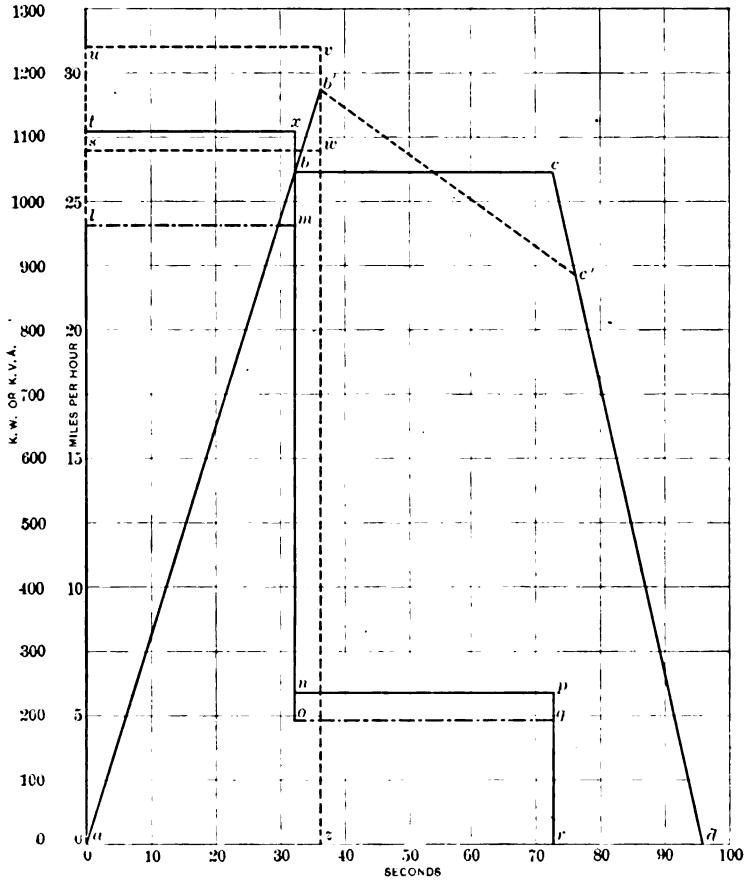
in the first cost to install direct current rotary converters instead of alternating current systems. In places, however, where the direct current railway system is not so fully developed, the difference in cost between the two systems might



a b c d AND *a b' c' d*: SPEED TIME CURVE.
a s w z: A.C. POWER INPUT; RHEO. CONTROL; NO RUN AT UNIFORM SPEED.
a u v z: A.C. K.V.A. INPUT; RHEO. CONTROL; NO RUN AT UNIFORM SPEED.
a l m o q r: A.C. POWER INPUT; RHEO. CONTROL; NO COAST.
a t x n p r: A.C. K.V.A. INPUT; RHEO. CONTROL; NO COAST.

FIG. 3.

not be so much, and that accounts for some European concerns installing alternating current motors.

To illustrate more fully the characteristics of the two types of motors, the following instance is considered, although it neces-

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sarily introduces some questions slightly outside of the scope of the paper.

A double track road with 27 stations is supplied power from a station located a distance from the tracks. Eight trains are running in each direction, which cover the entire distance in 52 minutes.

Weight of loaded train, including locomotive = 180 tons (2000 lbs.)

Weight on driving wheels, = 50 tons.

Thus maximum drawbar pull at 25% of weight = 25000 lbs.

Which corresponds to a maximum acceleration of two feet per second, per second.

Distance of run is 2560 feet.

Schedule speed, 15 miles per hour.

Maximum speed, 27 miles per hour.

Total distance is covered in 95.5 seconds, 20 seconds allowed for stops at each station.

No appreciable grades exist and effect of curves is negligible.

The three systems considered are:

A. The standard direct current railway system with series parallel control of the motors.

B. Three-phase induction motor system with rheostatic control.

C. Three-phase induction motor system with concatenated control in accelerating as well as braking.

Obviously when running at uniform and maximum speed one system offers no advantage over any other in energy consumption, assuming same efficiency of the motors (which is very nearly the case) while the volt-amperes taken by the motors are about 20 per cent. greater with the alternating current system (running at relatively light load).

While braking, the use of either of the first mentioned systems is immaterial, since no return of power can take place, but the third, that with concatenated control, offers some advantage in returning power which, however, is practically offset by the large current taken, and the complication of control and design of motor.

While accelerating, however, marked differences exist in the three systems, therefore the choice of one or the other is largely dependent upon the relative time of accelerating, running at uniform speed, and braking. Since, furthermore, the power required with any particular system depends upon the method of accomplishing the run, a number of schedules have been worked out, having about 1.2 ft. per sec. per sec. as an average rate of acceleration in all cases except Fig. 1.

So, for instance, in Fig. 1 are given three runs with direct current motors. Of these, Nos. 1 and 3 require more power than No. 2, therefore No. 2 run is referred to as the direct current motor run in the discussion following.

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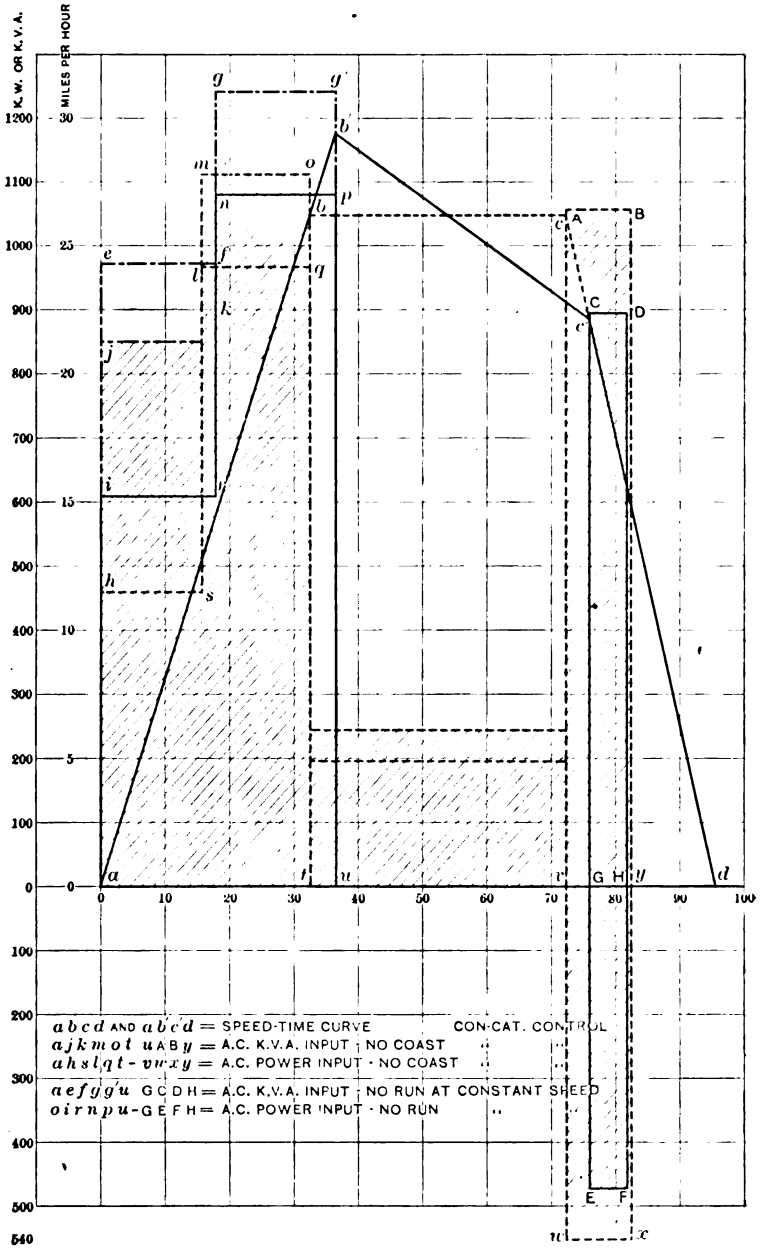

FIG. 4.

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In Fig. 2 are given what is considered the best alternating current runs. One curve shows the conditions with rheostatic control, and the other with concatenated control in accelerating as well as braking. These two curves will be referred to as the alternating current runs in the discussion following.

In Fig. 3 are given two runs with rheostatic control, both of which take more power than the corresponding run in Fig. 2, and are given merely to show that with widely different methods of running, the power does not vary more than 5 per cent.

In Fig. 4 are given two different runs in which concatenated control is used. These seem not so favorable as those in Fig. 2, therefore they are not referred to later except in the general table given below. The chief object of including them is to show the merits of coasting with concatenated motors. As should be expected, if the motors are connected in concatenation, when accelerating only, it is advisable to go up to as high speed as possible, and then coast without running at constant speed, whereas if power is returned by concatenation it is advisable to maintain the maximum speed until time of braking.

So, for instance, the least average power taken per run is found if the cars are not permitted to coast, but accelerated and retarded in concatenation, which power is only 15 per cent. more than the least direct current power. The apparent power is, however, 2.4 times as great. In view of this very large apparent power this method is not the most favorable, but that given in Fig. 2 is preferable.

The important results of the various runs are shown in the table given below, which undoubtedly is more comprehensive than the diagrams for a superficial investigation.

Columns A, B and C are most important, and show the conditions of the best runs Upon the constants given there and the corresponding curves the rest of the investigation is based.

Columns D and E show two direct current runs at different gear ratios.

Columns F and G show two runs with rheostatic control only.

Columns H, I and J show three runs with concatenated control in accelerating only.

Columns K and L show two runs with concatenated control in braking as well as in accelerating.

In going over the matter in more detail are considered the direct current run as shown in heavy lines in Fig. 1, and in Column A, and the alternating current runs with rheostatic and concatenated control as shown in Fig. 2, and Columns B and C.

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	A	B	C	D	E	F	G	H	I	J	K	L
	D. C. Series Parl. 33 Seconds Coast.	A. C. Rheostat 14 Seconds Coast.	A. C. Concat. 14 Seconds Coast.	D. C. Motors 43.5 Seconds Coast.	D. C. Motors 14.5 Seconds Coast.	A. C. Rheostat 40 Seconds Coast.	A. C. Rheostat No Coast.	A. C.—Concat. only when Accel. 40 Seconds Coast.	A. C.—Concat. only when Accel. 14 Seconds Coast.	A. C.—Concat. only When Accel. no Coast.	A. C. Concat. Brake and Accel. 40 Seconds Coast.	A. C. Concat. Brake and Accel. No Coast.
K. W. Seconds Accelerating	21800	31700	25100	22700	23000	39100	31100	30900	25100	22700	30900	22700
K. W. Seconds Uniform Speed		5400	5400				7800		5400	7800		7800
K. W. Seconds Braking			—3230								—2800	—5400
Total K. W. Seconds	21800	37100	27270	22700	23000	39100	38900	30900	30500	30500	28100	25100
Average K. W. per Run	190	322	237	197	200	340	338	268	265	265	244	218
K. V. A. Seconds Accelerating	21800	37000	33600	22700	23000	44900	35800	40000	33600	32100	40000	32100
K. V. A. Seconds Uniform Speed		6600	6600				9500		6600	9500		9500
K. V. A. Seconds Braking			7730								5400	10600
Total K. V. A. Seconds	21800	43000	47900	22700	23000	44900	45300	40000	40200	41600	45400	52800
Average K. V. A. per Run	190	379	416	197	200	390	394	348	350	362	394	454
Maximum K. W. per Run	780	977	977	912	735	1080	965	1080	977	965	1080	965
Maximum K. V. A. per Run	780	1140	1140	912	735	1240	1110	1240	1140	1110	1240	1110
Watt Hours per Ton-mile	70	120	88	73	74	126	125	99	98	98	91	81
V. A. Hours per Ton-mile	70	138	134	73	74	145	146	129	129.5	134	146	168
Ratio Average a-c K. W. / Average d-c K. W.		1.78	1.26			1.80	1.79	1.41	1.40	1.40	1.30	1.16
Ratio Average a-c K. V. A. / Average d-c K. V. A.		1.97	2.20			2.07	2.09	1.85	1.85	1.98	2.09	2.40
Average P. F.	1	87	57	1	1	87	86	77	75.5	73	62	48

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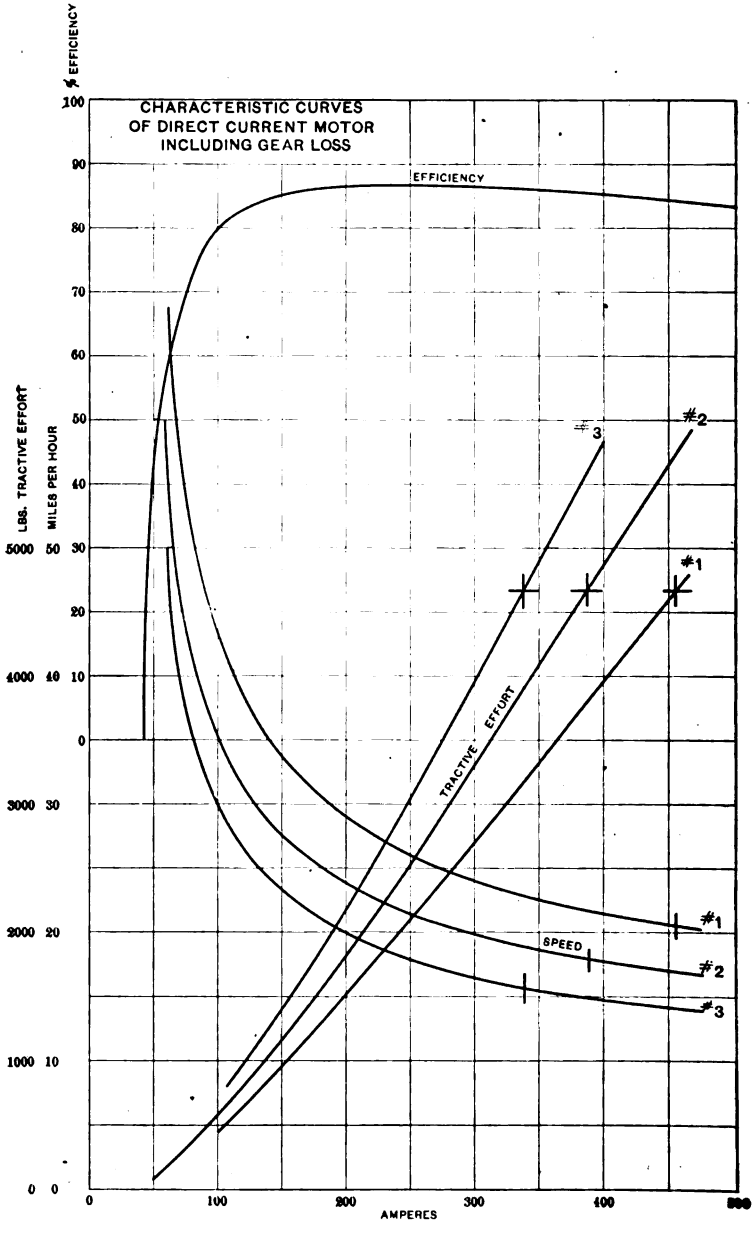

FIG. 5.

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The characteristic curves of the motors are shown in Figs. 5, 6 and 7. Fig. 5 gives the direct current motor curves, Fig. 6 the alternating current motor curves, and Fig. 7 curves of the same motors in concatenation. No special curves are given for this latter motor when used as generator to return power, since it is essentially the same as when used as motor.

To sum up the results, it is found from the various methods of running trains, first, that under apparently the most favorable as well as average conditions, the most economical alternating current system will take 26 per cent. more power and 2.2 times as

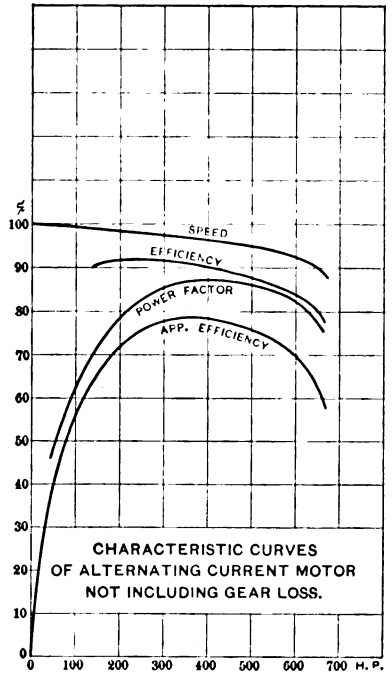

FIG. 6.

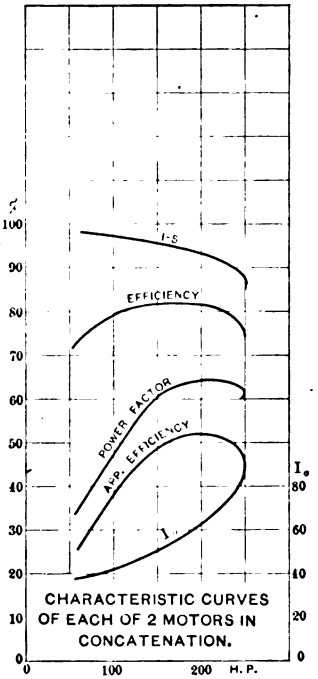

FIG. 7.

many volt-amperes as the direct current system. Second, that the concatenated control takes 26 per cent. less power but only 10 per cent. more apparent power than the alternating current system with rheostatic control. It must, however, be borne in mind that these values refer to power input at the motors, not the relations at the sub-stations and power-house, as will be seen later.

Power is supplied to four sub-stations located respectively 16,600 feet, 17,400 feet, 22,800 feet, and 35,000 feet from the generating station. The transmission potential is 11,500 volts.

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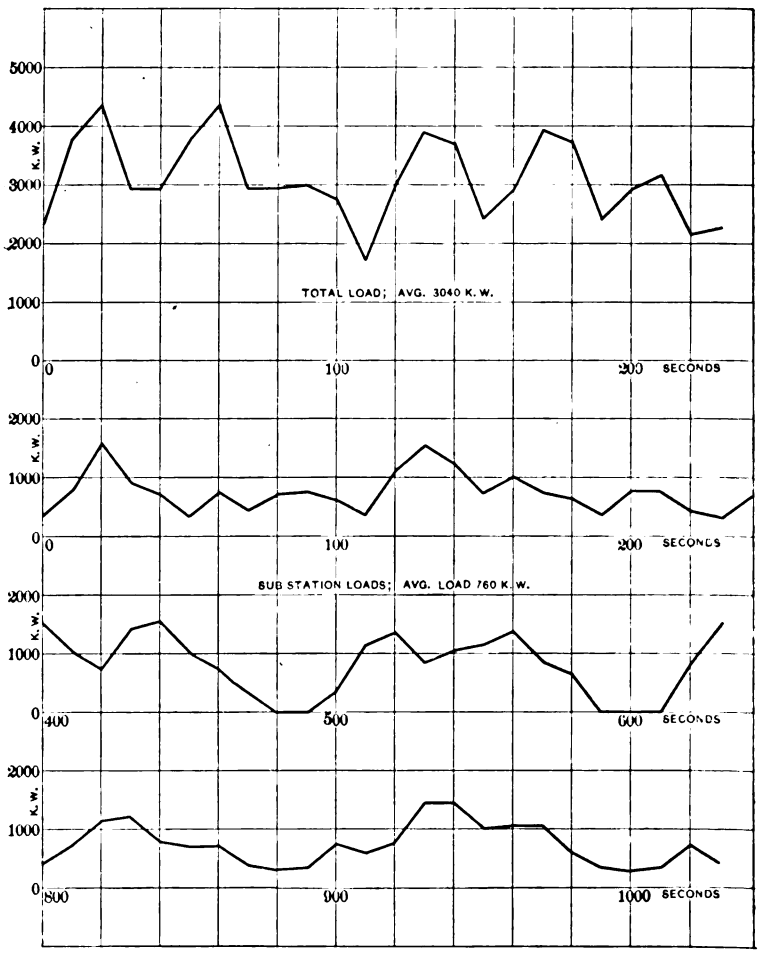
Capacity of Power House, Electrical Machinery, Lines, etc.—Since the supply of power is located at some distance from the receiving circuit, high potential three-phase generators are proposed in all three cases.



LOAD DIAGRAM
D.C. MOTOR; SER-PARALLEL CONTROL.
LOSSES NOT INCLUDED.

FIG. 8.

A. Direct current motors with series parallel control.

Installation.—The road bed has double tracks of 85-lb. rails and the combined cross-sections of feeders and trolleys for two tracks is 1 sq. in. of copper. In the calculations all tracks and

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feeders are assumed interconnected, and the feeder copper strung all around the track.

The resistance of steel rails is assumed as 12 times that of the corresponding copper, and that of bonds as 50 per cent. of rails. This gives the ohmic resistance of four rails in multiple between two sub-stations (average 17,100 ft.) as .09 ohms and the corresponding resistance of copper as .159 ohms, or a total resistance of .25 ohms.

Each sub-station has three 650 K. W. converters (one as spare) and ten 240 K. W. transformers. The high potential lines consist of two cables No. 0 B. & S. (one of which is spare) for each of the two distant stations and two cables No. 3 B. & S. for the two nearer stations.

Distance between sub-stations = 17,100 feet.

The transformers have two per cent. *I. R.* loss and one per cent. core lose. The converter has 94 per cent. officiency over considerable range of loads. The generating station has four 1,600 K. W. generators (one as spare) and engines.

Referring to Fig. 8 we find that neglecting losses,

	Killowatts.
Average load in K. W. on one sub-station is	760
Maximum load on one sub-station is	1600
Average load on the generating station is	3040
Maximum load on the generating station is	4400

This brings the average actual load on a rotary converter to 832 K. W.

Maximum load on rotary converter	1910
Average load on generating station	3650
Maximum load on generating station	5650

The converters run at 64% load at average load,
" " 146% load at maximum load.
The generators run at 76% load at average load,
" " 118% load at maximum load.

B. *Alternating Current Motors with Rheostatic Control.*—The motors are supplied power from four sub-stations at an average potential of 3,000 volts over two sets of three-trolley wires, No. 00 B. & S. (interconnected). Each sub-station has four 700 K. W. transformers (one to spare). The high potential lines are two sets of No. 00 B. & S. and No. 2 B. & S. respectively for the longer and shorter distances.

The generating station has five 1,800 K. W. three-phase 11,500 volt generators and five 1,600 K. W. steam engines.

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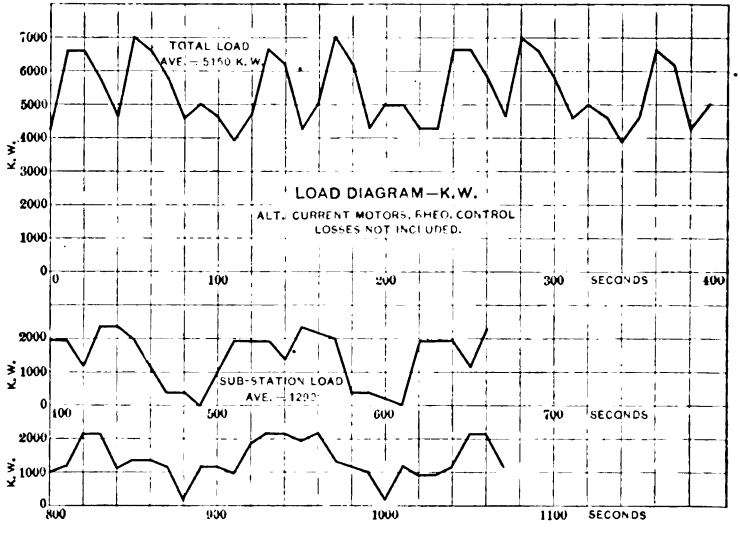

FIG. 9.

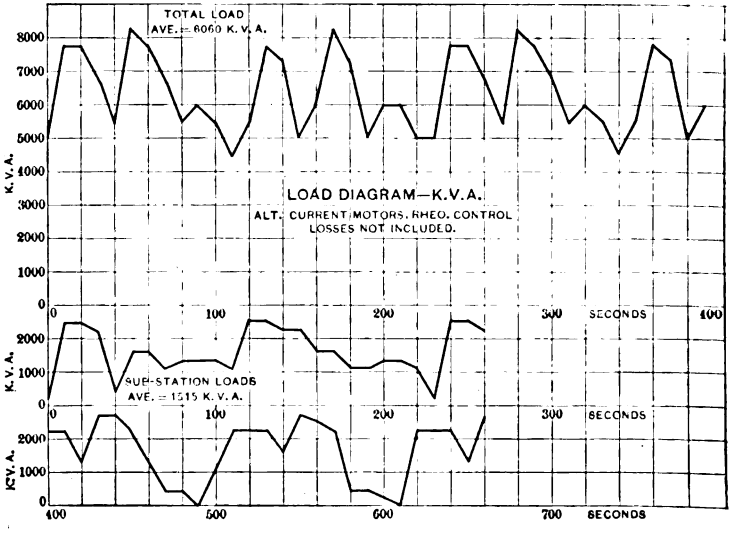

FIG. 10.

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From the load diagrams, Figs. 9 and 10, is found that neglecting losses,

	Killowatts.
Average power on sub-station is	1290
Average K. V. A "	1515
Maximum power "	2300
Maximum K. V. A. "	2800
Average power generating station is	5150
Average K. V. A. " "	6060
Maximum power " "	7100
Maximum K. V. A. " "	8300
This gives an average K. W. output of power station	5600
" " K. V. A. " " "	6500
" maximum K. W. " " "	7780
" " K. V. A. " " "	8880

The generators will run at 90% load at average load,
" " 123% load at maximum load.
The engines will run at 92% load at average load,
" " 126% load at maximum load.

C. *Alternating Current Motors, Concatenated Control.*—The secondary net work is laid out as in previous case, but the high potential lines are duplicate sets of No. 000 B. & S. and two No. 000 B. & S. cables in multiple for the shorter and longer distances respectively.

Each of the four sub-stations has four 800 K. W. transformers. The power station has five 2,000 K. W. generators and five 1,400 K. W. engines.

From the load diagram, Figs. 11 and 12, is found that neglecting all losses,

	Killowatts.
Average power on sub-station is	948
" K. V. A. "	1660
Maximum power "	2000
" K. V. A. "	3500
Average power on generating station is	3800
" K. V. A. " "	6650
Maximum power " "	6000
" K. V. A. " "	10000
This gives an average K. W. output of power station	4170
" " K. V. A. " " "	6850
" a maximum K. W. " " "	6000
" " K. V. A. " " "	10000

The generators will run at 85% load at average load,
" " 125% load at maximum load.
The engines will run at 75% load at average load,
" " 107% load at maximum load.

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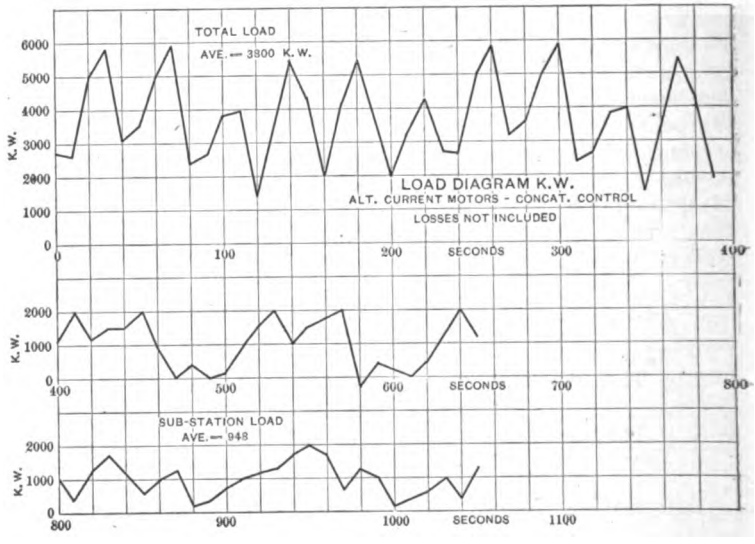

FIG. 11.

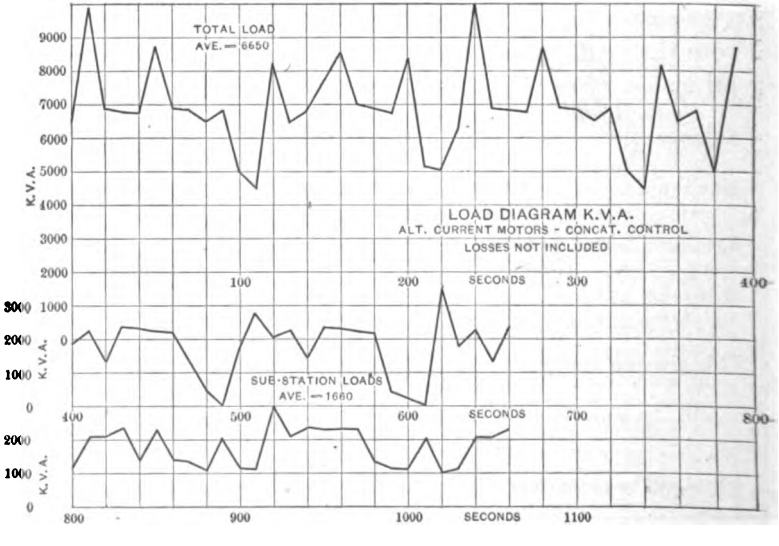

FIG. 12.

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The selling prices of the various items referred to are assumed as follows:

Complete steam equipment, including installation.	$75.00 K.W.
High potential generators, switchboards and instruments	26.00 "
Rotary converter sub-stations and apparatus	40.00 "
Transformers (700 K. W.)	4.50 "
Direct current electric locomotive complete	$15,000.00
Alternating current electric locomotive complete.	19,000.00
Passenger coaches (70 seats)	4,500.00
High potential cables (10,000-v.) No. 000 B & S.	1,060.00 per M. ft.
" " " " " 00 "	930.00 "
" " " " " 0 "	840.00 "
" " " " " 1 "	710.00 "
" " " " " 2 "	650.00 "
" " " " " 3 "	600.00 "
Copper	.186 per lb.
Direct current trolley construction	900.00 per mile.
Alternating current trolley construction	1,200.00 "
85-lb. rails, per ton	26.00
Track construction	500.00 per mile.

EXPENSES OF INSTALLATION AND AMOUNT POWER REQUIRED.

A. Continuous current motors with series parallel control.
B. Alternating " " " rheostatic current.
C. " " " " concatenated control.

	A	B	C
Power house steam equipment	$480,000	$600,000	$525,000
" electrical "	166,000	234,000	260,000
	646,000	831,000	785,000
Rotary converter station	312,000	....	....
Transformers	....	50,500	57,500
	312,000	50,500	57,500
17 locomotives, complete	225,000	322,000	322,000
68 passengers coaches	306,000	306,000	306,000
	531,000	628,000	628,000
Cables, duplicate	157,000	172,000	366,000
Trolley and feeder copper	49,000	31,000	31,000
	206,000	203,000	397,000
Track, material and construction	109,000	109,000	109,000
Trolley construction	23,400	31,200	31,200
	132,400	140,200	140,200
Total cost	$1,857,000	$1,856,000	$2,008,000

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Average K. W. power required.....	3650	5600	4170
K. W. average loss.....	600	440	380
% loss.....	16.4	7.8	9.1
Percentage of d. c. power.....	100	153	114
Percentage cost of d. c. installation.	100	100	107

It is thus apparent in this particular instance, which is fairly respresentative for heavy urban work, that the direct current system offers decided advantages in economy if installed at the same price as the alternating current system, and that the same economy cannot be obtained with alternating current, no matter at what cost, furthermore, that the alternating current system with concatenated control is preferable to that with rheostatic control. It must, however, be borne in mind that for an actual installation, practical conditions might warrant different amount of machinery and different units, and that allowances must be made for sharp turns, grades, etc., and that the prices given are somewhat arbitrary. The three systems are, however, placed on as nearly as possible the same footing, so that the comparison should be fair, even if the actual cost of the installation is considerably different.

To conclude, it might be stated that due to the favorable characteristics of the direct current railway motor and the rotary converters, compared with the alternative current motor for this class of work, very few propositions warrant the use of the alternating current throughout. Indeed there is no question that the stand taken by the American engineers in this matter in recommending rotary converter systems almost exclusively, is correct and warranted by considerations of economy and first cost, no matter what the adverse criticisms have been of late. There is undoubtedly a field for alternating current motors, but it is strictly limited to long distance schemes with very few stops, or to mountain roads.

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Discussion.

[Discussion on the papers of Messrs. Armstrong and Berg, Buffalo, Aug. 24, 1901.]

President Steinmetz:—Gentlemen, before proceeding to the discussion of these two papers, I will call upon Mons. Janet, who desires to say a few words to you.

Mons. Paul Janet:—Now that my technical remarks are ended, I must not forget that to-day is the day of parting, and that soon we shall leave each other for a long time. Some two weeks ago, in New York, I was expressing to you, in the name of my fellow-countrymen, all the sentiments that your warm welcome had inspired in us; since that time you have overwhelmed us with the most delicate attention; the day passed in New York, on the East River, the sail on the Hudson River, the charming reception at Schenectady; in a word, all this entire week passed in Buffalo, Niagara, at the Exposition, in the various stations of the city, all that will leave ineffable recollections with us. The technical visits that we have been able to make in company with you have been highly instructive to us; we have especially admired the magnitude and power of your installations, and, in each of them, the great care which has been devoted to the study of the equipment. This portion, which was formerly considered a mere accessory, assumes to-day the highest importance, and we have been struck with the considerable efforts that you have made to bring it to the same degree of perfection as the steam engine and the dynamo; the switches, the circuit-breakers, all the control and safety appliances, become real machines, really mechanical and robust in construction, and they take the important place which belongs to them.

It would take too long to enumerate here all the other objects of our remarks; this will form the material of a report that we will prepare on our return. For the moment, allow me to express to you, for the last time, the sentiments of profound gratefulness that we feel for our reception, and the hope that our trip will have contributed to secure, in a more intimate manner, the bonds of fraternity between the American Institute of Electrical Engineers and the Société Internationale des Electriciens.

President Steinmetz:—Gentlemen, I believe you will join with me when I assure Mons. Janet that the pleasure has been mutual, and while we are very glad to have been able to make him comfortable here and to entertain him, we have profited just as much by his presence and the presence of his friends, because there is nothing which broadens the views of men, especially of engineers, so much as intercourse among those who have studied the same problems from different points of view or in different countries; and beside this, the intercourse which now exists between ourselves and our friends from abroad, is a

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means of strengthening the bond which ever has connected all the engineers, all the scientific men, from the various countries with one another and is the outward sign of the unity of interest and the unity of ideas and of sentiment existing between them.

Gentlemen, before proceeding with the next paper, I call upon the Secretary to read some resolutions which have been brought up by the Library Committee for your further action.

Secretary Pope read the following resolutions:

WHEELER RESOLUTIONS.

Whereas, Dr. Schuyler Skaats Wheeler, a life member of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, has purchased the extensive collection of electrical books and periodicals, made by the late Latimer Clark, and has presented it to the INSTITUTE, on certain conditions as to its future preservation and maintenance; and,

Whereas, The Council of the INSTITUTE has accepted the gift on the terms stated by the donor; and,

Whereas, The library, which thus becomes the property of the INSTITUTE, comprising 2,048 bound volumes of books, 3,150 bound pamphlets and 1,378 volumes of periodicals, is the most complete collection of early electrical literature in the world, being especially rich in the rare publications of the seventeenth and eighteenth centuries, and containing practically all modern works up to 1886; now, therefore, be it

Resolved, That the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS hereby acknowledges to Dr. Wheeler its high appreciation of this magnificent gift, and of the generous spirit which he has shown in thus placing this valuable library at the service of his fellow-members, and at the same time laying such a substantial foundation for the future library of the INSTITUTE; and be it further

Resolved, That these resolutions be engrossed, and that one copy be presented to Dr. Wheeler, and another copy be suitably framed and hung in the Library of the INSTITUTE.

CARNEGIE RESOLUTIONS.

Whereas, The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, through the generosity of one of its life members, has become the owner of the Latimer Clark electrical library, containing almost 7,000 titles of books, pamphlets and periodicals published prior to 1886; and,

Whereas, In order to make the library of the greatest use to all members of the INSTITUTE and to the electrical profession generally, a large sum of money was needed for the preparation of a printed catalogue and for the purchase of additional volumes; and,

Whereas, Mr. Andrew Carnegie has generously contributed $6,880 for these purposes; now, therefore, be it

Resolved, That the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS hereby expresses to Mr. Carnegie its high appreciation of his generous gift and of the interest which he has shown in the welfare of the INSTITUTE by thus assisting in so substantial a manner to establish and make accessible a library

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which shall contain the entire literature of electrical science; and be it further

Resolved, That these resolutions be engrossed, and that one copy be presented to Mr. Carnegie, and that another copy be suitably framed and hung in the library of the INSTITUTE.

MR. MAILLOUX:—I take pleasure in moving the unanimous acceptance of these resolutions.

MR. C. A. BRAGG:—I second the motion, Mr. President.

[Carried unanimously.]

PRESIDENT STEINMETZ:—Gentlemen, discussion is now in order on the papers of Messrs. Armstrong and Berg. We have here with us several prominent engineers from foreign countries, who undoubtedly have given the problem of three-phase alternating current railroading a good deal of attention, and we should be very glad to hear from them. Mons. Gillon, will you not say a few words to us?

PROF. G. GILLON, (University of Louvain, Belgium): [Translation]—I regret very much not to have sufficient knowledge of English to be able to express myself in your language, but that would be all the more difficult, inasmuch as your President has called on me unexpectedly, in consequence of which I would be much embarrassed to tell you anything interesting. I do not possess any personal experience on the subject which is at present before us, but I have had occasion to follow, from quite near, some recent experiments which are still in process at Berlin. These experiments relate to electric railroad traction at very high speed (125 miles per hour). It is noteworthy that for a long distance line which requires locomotive capacity of 1,600 h. p. normal output, we could scarcely think of utilizing continuous currents at 500 volts, since the expense for copper and the number of sub-stations would both become entirely too great.

It is, therefore, natural to think of triphase currents at 10,000 or 12,000 volts, especially since the principal objection to the triphase motor, notably that of starting with difficulty and of absorbing a large amount of energy on grades as the result of its speed constancy, would disappear in certain cases, for example—that of a long line at very high speed on ground having few slopes and where only few stops are necessary. Under these conditions I see a future quite near and quite extensive for traction by means of triphase electric motors. It is this conviction which has led the firm of Siemens and Halske to make certain experiments, of which I will say a few words.

About two years ago, this firm put on trial on a line two miles long, a locomotive of 300 h. p. capacity, taking current at 10,000 volts from a triphase overhead line by means of three rubbing trolleys. The high tension current from the line passes through the transformers which furnish it to the motors at 700 volts. I have had occasion to see this locomotive in operation. Its

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starting is rapid enough, and the trolleys make satisfactory contact with the line, although it should be stated that the speed was only about forty miles; in consequence of the short length of the line it was naturally not possible to attain higher speeds, but these experiments seem nevertheless to have proved the possibilities of a triphase line operating under 10,000 volts, notably from the standpoint of circuit insulation of the trolley connections and of the current and power control. It remains, however, to be established whether the speeds desired can be attained, and especially whether these speeds will be attained with an economically possible efficiency. It is in order to establish these points that the firm of Siemens and Halske has constructed a motor car of 90 tons, with 4 motors, having an aggregate capacity of 3,200 h.p. in starting, and 1,600 h. p. mean working output. This would constitute by itself a high speed train having seating capacity for 60 to 70 passengers. It must be, by this time, actually constructed, and will be tried shortly on a line of 28 miles between Berlin and Zossen. Some analogous experiments will likewise be made by the Allgemeine Electricitäts Gesellschaft on this line. It is to be hoped that these efforts will be crowned with success and that the electrical industry will see opening to it an avenue of usefulness as new as it is important.

PRESIDENT STEINMETZ:—Gentlemen, we have listened to Mons. Gillon's interesting remarks. Now we should like to hear from another country. Perhaps Dr. Janisch can enlighten us further, as he is connected with the Siemens company which has done quite a good deal of experimenting in railway matters.

DR. JANISCH:—I am, unfortunately, not in the position to give you material information in regard to the question under discussion, since I am not directly connected with that department of Siemens and Halske which is making comprehensive experiments on this subject. I know that my firm is running an electric locomotive with 10,000 volts three-phase current and maximum speed capacity of 140 miles per hour experimentally on an experimental track in Gross-Lichterfelde in the neighborhood of Berlin.

So far as known to me, these experiments are to be carried on in common with other electric companies of my country on the railway line between Berlin and Zossen. The extent to which the industrial utilization, on a large scale, of the experimental results obtained may become possible in the future, depends in reality on the encouragement of our authorities, who, unfortunately, are not always disposed to follow the rapidly advancing technology with intelligence, and do not always understand how to impart to a healthy development of our industry that propelling force which you here call "push," and which has made you so great in such a remarkably short time.

I beg you for to-day to be satisfied with the small amount of information which I am able to communicate to you, and beg to

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be allowed, after my return to Germany, to communicate more complete information, perhaps, in your TRANSACTIONS, concerning the character and results of our experiments. I still have to thank your President most heartfully for the exceedingly great honor which your highly honored society has done me by singling me out to be its guest during this meeting, and this thought accompanies a hope, that if it should be my privilege to attend some of your future meetings I may not only profit by your abundant experience, but that I may myself be able to contribute something from my own country which may be interesting and useful to some of your honored members.

In conclusion, I permit myself to thank you most heartily for your personal efforts in my behalf, and beg you to accept my kindest regards with special consideration.

MR. BION J. ARNOLD:—Mr. President, I am very glad, indeed, that the representatives here from foreign countries were brave enough to get up and say something in favor of the three-phase railway, for we of this country have been somewhat slow in this field, and seem here to-day to have pretty thoroughly buried the alternating motor for railway work. I am very sorry to see it. While I may not be ready to advise others to put into practice what I really believe at the present time, and since we are all more or less the creatures of our environments, I might advise differently from what I actually believe, in order to conform to the conservatism necessary for a safe, advising engineer. I am, nevertheless, a believer in the future of the alternating motor for heavy railroad work. I have been, in turn, a friend of the steam locomotive, the storage battery and the rotary converter substation, and have used many of each of them in various plants. For this reason I believe I am in a position to consider the matter from a fair standpoint. I am now in favor of the alternating motor on railroad trains, notwithstanding the fact that it does not seem to have many friends here to-day. How we are going to use it, I am not prepared to say. I am not at all certain that I shall suggest a solution, but I believe somebody will do it. I do not want to admit that the inventive talent employed by the large electrical manufacturing establishments of this country is unable to solve this problem, and I believe if left to itself with a free hand, that it will do it. We have been handling this electrical question, from the railroad standpoint, differently from what I believe it should be handled. The electric motor, primarily, is a constant speeded machine, most efficient at a constant load, and designed to run from a constant pressure. We have been, up to the present time, endeavoring to make it start its load by throwing energy from this constant source, corresponding in hydraulics to a high head of water, into it in great chunks, to use a crude expression, and then letting it dissipate the unutilized energy in the form of heat on itself, or through auxilary resistance, in order to hold back this destructive force until the motor can get

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its speed sufficiently high to protect itself. I think this is wrong. It may do for small units, such as we are running street cars with. It may do for electric elevators, where the loads are light. It will not do for heavy trains.

My opinion is that we must in some manner use this, at present, dissipated energy to assist in starting the trains. When we do that, I believe the alternating current motor will pull our railroad trains.

Now, in regard to this paper of Mr. Berg, and the paper of Mr. Armstrong, I want to say that I thoroughly appreciate the amount of work it has taken to give us the information contained in them. It certainly is valuable information. I do wish, however, that Mr. Berg had taken an example of a railroad, which would be a little bit more fair, in my judgment, to the alternating motor. I do not doubt that his intention has been to be perfectly fair, but I do believe that, if he had taken a little greater distance into consideration the figures would have been different. He has taken quite a short road, and a road fairly well adapted to the direct current system. I have no doubt Mr. Berg will answer this, and give us the information I am looking for: *i. e.*, what the conditions were under which these calculations were made, and whether or not a greater distance would have modified these figures. As to his conclusions, for slow speed railway systems such as we are operating in our cities to-day, I think he is correct. I do not think that there is anything that can equal the direct current for such work. Certainly the rotary converter sub-station direct current motor system is better than any other existing plan for interurban roads with light trains, although I believe that the cost of such a system is too great and that it will ultimately give way to the alternating motor system. But when we get into heavy railroad work, where we want to start a heavy train from one terminus and run it through to another terminus at high speed, with few stops, it seems to me the alternating motor is the ideal thing for it. I am looking for the manufacturing engineers of this country to solve that problem.

MR. MAILLOUX:—Mr. President and gentlemen, I have listened with a great deal of interest to the presentation of the papers by Mr. Berg and Mr. Armstrong, and also the remarks which have been made, more especially by my colleague, Mr. Arnold. Mr. Arnold and I had the pleasure of visiting together many polyphase railroad installations in Switzerland last year. We both came home permeated with the idea that the future belonged to the polyphase current. Mr. Arnold, I see, is still quite saturated with that idea. I have had some experience within the last few months which has tended greatly to demagnetize me in that respect. I will not dispute the fact, well recognized, and which has been adverted to by our colleague from Belgium, Prof. Gillon, that for long distances, whether the speeds be high or low,

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the alternating current is extremely well suited. It offers many advantages in the generation, the distribution and the utilization of current. There are, however, problems in electric railroading, in cases where it is desired to give a high speed service on relatively short runs, which practically preclude the use of the alternating current motor, in the present state of the art; and I think that in this case one might say that the greater the schedule speed which is to be maintained, the more difficult it is to utilize and apply successfully the alternating current motor. The limitations depend upon the distance run and the speed to be attained in that run.

The curves in Fig. 2 of Mr. Berg's paper give a very interesting comparison, which serves usefully to diagnose the case, so to speak. In this figure Mr. Berg has superposed two diagrams of acceleration, one being the diagram of acceleration of a direct current motor, and the other that of an alternating current motor, both of presumably equivalent capacity and intended for the same service.

The ordinates (y) of these acceleration curves represent speeds, in miles per hour, and the abscissæ (x) represent time in seconds, counted from the instant that the car begins to move.

The rising portions of both curves are shown straight in Fig. 2, although we know that practically they cannot be straight since one of the factors, namely, the train resistance, is not constant, but varies with the speed. In reality, the two curves should both be slightly concave toward the axis of x, although the difference is small, and, for the purpose of comparison, may be negligible. The differential co-efficient of the rising portion of each curve; that is to say, the ratio of any increment of speed to the corresponding increment of time is, in either case, a measure of the change in speed; in this case, of the gain in speed, stated in miles per hour. The straight lines in this case are tantamount to the assumption that the rate of acceleration is constant until the speed line ceases to be straight. In practice it is very nearly constant. The portion of area of each acceleration curve comprised between zero time and any given time, is, as is well known, a measure of the distance covered by the car in the corresponding time. The distance covered, when calculated and plotted for each time value, gives the distance curve or integral curve, so-called.

Mr. Berg has given at the upper part of the diagram such a distance curve, which I presume, in this case, is the distance curve corresponding to the alternating current motor. It is to be regretted that he did not also plot the integral curve for the other motor, whichever it was; because it is precisely in the comparison of the integral curves that one learns the most useful lessons in regard to the relative advantages of the two systems of motors, especially for high speed service. If both curves had been plotted, the two curves would show a difference in their rates of rise at the beginning.

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This difference in rates of rise of the two distance curves is a necessary mathematical consequence of the fact that the two acceleration curves do not coincide, but rather diverge as they rise from zero; in each case the rate of rise, or the differential coefficient (dy/dx) of the integral curve being directly proportional to the height (y) of the acceleration curve at the same time point (x). This difference in rates of rise of the two distance curves is, therefore, related to the fact, plainly visible in Fig. 2, that the two acceleration curves have humps or crests which do not occur at the same time points.

Now, the two superposed acceleration diagrams, taken with their corresponding distance curves, afford a criterion and comparison of what might be termed the "efficacy of acceleration."

The motor whose distance curve shows the greater rate of rise at the beginning is, of course, the motor which has the more rapid acceleration, for the distance curve shows that it then covers more distance per unit of time. The rapidity of acceleration depends, as is well known, on the steepness of the rising portion of the acceleration curve; in other words, on the angle which the mean direction of the acceleration curve makes with the axis of x in the rising portion, which angle might be called the "initial angle of acceleration," the tangent of which (y/x) is substantially equal to the mean rate of acceleration; *i. e.*, the gain in velocity (miles per hour) per second.

When, as in high speed, rapid transit service, with relatively short runs and high schedule speed, the motor has to make so many starts and runs so little time at full speed that it practically does most of its work on the early part of the acceleration diagram, then, evidently, that motor, and that motor alone, should be selected which can give the greatest initial angle of acceleration, and which consequently soonest can give the maximum rate of rise to the integral or distance curve.

The two acceleration curves in Fig. 2 show quite a divergence in their ascending portions, the "initial angle" of acceleration being greater for the d. c. than for the a. c. motor. This divergence would be much greater still if the diagrams had been made especially for the purpose of comparing or contrasting the time-saving or schedule speed-making possibilities of the two types of motors instead of their economic merits in a case where the schedule speed is inside, although near, the limits of the a. c. motor.

The real reason why the a. c. motor is not as good as the d. c. motor for high speed rapid transit service is simply that the initial angle, or mean rate of acceleration, cannot be made as high as that of the d. c. motor. Its limitation in this respect is due to the fact that the present a. c. motors can develop a maximum starting torque of from two-and-a-half to three times the normal full load torque only, whereas a d. c. motor can develop a maximum starting torque equal to five, six, or more times the

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average normal running torque. The starting torque of a d. c. motor is, indeed, only limited by the current which one dares to send through it at the time of starting. The curve of tractive effort, as a function of the current, usually shows that the torque increases faster than the current, or that the pull per ampere is actually higher at the limiting current value than at the running current value. As a matter of fact, one may, and does, in emergencies, for very short times, pass larger currents through a d. c. motor than would be usually allowable or necessary, thereby obtaining a tractive effort of as much as eight, nine, or even ten times the mean effort. In the case of the a. c. motor, as pointed out, one is limited, and cannot get a torque beyond that which the impressed e. m. f. can produce. Now, looking again at the two acceleration curves, we see that since the area of the diagram represents distance, the more quickly we can fill up that diagram; that is, the less time we lose in climbing up to full speed the more area we enclose and the more distance we cover in a given time. That is the mathematical reason why we must have an acceleration curve as steep as possible. That can only be obtained by having a motor which will give as large an amount of net tractive effort as possible; that is to say, having a motor which, after having allowed for the tractive effort (pounds pull) necessary to move the car against the axle friction, the rail friction, and the wind friction (*i.e.*, the train resistance), shall give as many *net* pounds as possible, because these only are the ones which are necessary and serviceable for acceleration.

This net pull produces and represents the energy that is to be put into the car in the form of momentum. It must come out of the electric circuit in some form, and I cannot conceive of any way in which we can juggle with the circuit so as to get this energy without expanding it or drawing it from the circuit. Reference has been made to elevator motors, and to means of starting with lower currents. In the case of a car, we have so many tons of mass to which a certain velocity must be given in a relatively short time. That requires a definite amount of mechanical energy (foot pounds) to be generated in the time, and it is therefore the rate at which we can produce those foot pounds and put them into the train that determines the acceleration.

The electrical manipulation of the motor circuits and windings, or the resort to mechanical expedients and accessories like shaft-clutches, gears with variable speed ratios, etc., is only useful to the extent that it improves the efficiency of conversion of electrical into mechanical energy, thus enabling a given motor to produce more mechanical output from a given electrical input; and since the benefit, if any, from these features would be shared by both types of motors, their relative situation would, therefore, not be materially changed thereby. So far, my investigations have resulted in the disappointing conclusion that it is impossible, in relatively short runs, to obtain a

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mean angle of acceleration sufficiently steep with the a. c. motor to make it possible for us to hope to produce with it the schedule time required for high speed service. If the run is relatively long it can be done; but I have found that on runs of a mile, a mile and a half, and perhaps more, the difficulties of obtaining a rate of acceleration sufficiently high are so great that the manufacturers give us little or no hope of the immediate solution of the problem. Therefore, while I, myself, started out with the preconceived idea of the great advantages of the alternating current system, and could point as an incentive to very many interesting examples in Europe, yet I am forced to the conclusion that for most cases "the time is not yet." The paper of Mr. Berg, and I think that of Mr. Armstrong, cited cases of mountain railroading where the alternating current system is particularly applicable; but unfortunately these are not the conditions which obtain in the cases which engineers have to deal with at present. They are cases which apply to the future rather than to the present. It will doubtless be necessary for us to demonstrate the feasibility, applicability and practicability of electric railroading on a large scale, on much smaller roads and under vastly different conditions before the roads where the conditions are apparently so ideally favorable can become interested in it.

PROF. GILLON:—I think that I have understood that my friend Mr. Mailloux has spoken of the application of high speeds to lines having frequent stops, such as for metropolitan elevated and underground lines. It seems to me that for short distances, there is hardly any object in exceeding speeds of 60 miles an hour, for the expenditure of energy which would be required for a too rapid acceleration would not be justified by the very small amount of time gained in short distances.

The normal sinuosity (*i. e.*, the unavoidable curves) of said lines will limit, in general, the maximum speed to a speed below 60 miles.

I think Mr. Mailloux has stated that it was possible to obtain direct current motors capable of developing in starting a torque seven or eight, or even nine times the normal running power, whereas the maximum torque of triphase motors does not exceed two and one half times the normal torque.

I admit the existence of such direct current motors, assuming that suitable precautions are taken to avoid the heating of the insulation and sparking at the brushes, but I would call attention to the fact that in the transformer motor car, one can increase at will the starting torque of triphase motors. It is sufficient for this to raise the e. m. f. applied at the terminals of these motors by inserting a few supplementary winding turns. In the secondary of the transformers this is more especially possible, inasmuch as the starting torque increases in proportion to the square of the applied e. m. f.

MR. E. P. ROBERTS:—I desire to ask one or two questions and

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to make a few remarks from a similar standpoint to that of Mr. Arnold, who is a designer of electric roads. It has been stated that the polyphase system with induction motors is especially applicable to long hauls at constantly maintained speed. In Ohio, where we have a number of electric railways, we have no such roads. We do not at present have very long roads; *i. e.*, roads of over 50 miles, though we shortly will have; but we do have quite long roads with high speed schedules and comparatively few stops, and one of these roads also operates at the same time a medium speed schedule having a greater number of stops, and this road has only a single track; in other words, the roads are already so long as to require both rapid through service and local cars stopping at all towns and villages, and quite often in the country.

Relative to sub-stations, we are all hoping that it will be possible to do away with these and not have an interest account on the investment in rotating machinery and also a depreciation and repair account on them, and, in addition, the payment of salaries for attendants. Capitalizing salaries and adding it to the cost of machinery makes the total first cost of sub-stations a very considerable percentage of the total cost of an interurban electric railway, and a great increase per mile as compared with ten to fifteen mile direct current roads.

As Mr. Arnold stated, we must look to the manufacturers to obtain machinery to accomplish the results desired, and if they could do away with sub-stations there would be a number of us much pleased; but I have been considerably disappointed, both from the statements made here and lately to us in our office, as to the probability of doing away with sub-stations on the ordinary interurban road, operating under the conditions which generally exist. The amount of power now taken, both average and maximum, and at starting, is very considerable, and if by doing away with sub-stations we must not only increase the first cost of the generating machinery but also of the line work and of the car equipment, it is not improbable that the present system is, in most cases, the better, particularly taken in connection with such matters as being able to operate at variable speed and over existing trolley roads, etc.

The following figures taken from car measurements recently made by assistants in our office may be of interest. They are the results of measurements of 500 miles of run over four roads, each of which has cars of approximately the same size and weight, with four 50 h. p. motors, the difference being mainly in the gearing, maximum and schedule speeds, number of stops per mile and grades of road.

Road No. 1—High schedule and maximum speeds, level road.
" No. 2—Medium schedule speed, level road.
" No. 3—Medium schedule speed, considerable grades and curves.

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Road No. 4—Medium schedule speed, heavy grades and curves.

Schedule speed is exclusive of lay-over at end. Running speed is speed when in motion. K. W. is at the car.

	SPEED.			Average stops per mile in country.	k. w. per mile.		Average k.w.	
	Schedule.	Max.	Running.		In country	In city.	In country	In city.
No. 1—	26.2	55	41	.85	2.88	2.11	73.3	21.1
No. 2—	20.5	43	32	1.41	2.85	2.27	56.8	21.6
No. 3—	20.4	39	25	.70	2.18	3.36*	48.5	26.5
No. 4—	20.6	47	24	.56	2.18	2.32	47.8	23.4

*Unusual load and stops.

SPECIAL NOTES—Max. C.—400 amp. on No. 1—starting, and No. 3 accelerating on grade—Max. grade on No. 3—12 per cent. about ½ mile, and taking 15.7 k. w. per car mile.

One of these roads is the one already mentioned where, on a single track, two schedules are simultaneously maintained; *i. e.*, in addition to the regular schedule, the cars of which stop at all towns and villages and a number of stops in the country, through cars are also operated, stopping at only one point between terminal points and not stopping at all in the country.

Relative to locating sub-stations, when designing a new road on which traffic has not been developed, we are confronted with the fact that the fewer the number of cars—in other words, the greater the headway—the more economical it is to have the sub-stations a considerable distance apart, it being cheaper to pay interest on additional feed wire rather than to install numerous sub-stations; but, as the traffic increases, it is preferable to have more sub-stations; therefore, how much to discount the future is a serious question. It is, of course, practicable to change the location of sub-stations, but it is quite an expense, particularly if storage batteries be used.

The designer of electric roads is dependent upon the manufacturer as to what machinery he can obtain to accomplish the desired results. It is not so much a question as to how the results are obtained, as to the certainty of the first cost and cost of operation, and whether the details have been so thoroughly worked out and proved in practice, that they will not only operate with the guaranteed efficiency, but also with reliability.

MR. MAILLOUX:—Mr. President, the remarks which have been made since I spoke show the importance of one qualifying his statements and referring somewhat to conditions, since, as I pointed out in a previous discussion, one cannot rightly compare things under different conditions. It is, perhaps, necessary for me to state that what I referred to by the expression "high

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speed" was not the extremely high speeds which Prof. Gillon adverted to, namely those of 100 to 150 miles per hour, nor yet was it the speeds which are usually referred to and meant by "high speeds" in interurban or suburban work. I referred to speeds which are called high because they seem high by comparison with existing speeds. I mean the speeds of rapid transit service on interurban and suburban lines, that would reach as high as 45 to 50 miles per hour, *schedule* time. These would necessitate a maximum car speed of somewhere between 60 and 80 miles, according to the condition of the road, (the curves, grades, etc.).

I do not wish to be understood as stating that I have lost entire faith in the alternating current motor, or that I have lost all hope of its fulfilling the mission to which Mr. Arnold looks forward with so much hope and confidence. I wish to state that, in many respects, I still regard it as the ideal system, and that I would be pleased extremely to have it shown to me to be feasible for cases of the character I have reference to.

Now, if you again look at the instructive diagram on page 468, you will see that, from the nature of the two curves, the point at which the two distance curves will come together would be somewhere between 60 and 80 seconds; in other words, nearly or only at the end of the run; because they would cross only when the area included between the two rising parts of the curve was equalled by the area of the upper portions of the curve; and that point you can see readily must be somewhere beyond 60 or 70 seconds. I submit that, in most cases in which high speed traction is of interest to us, we must, inside of 70 seconds, have reached the maximum speed at which we are to run, and in many cases we have already reached a speed at which we are obliged to turn off the current; and we readily see that the shorter the run the earlier is the time at which we must shut off the current. Now, if we wish to cover a certain distance in a very short time, it is absolutely necessary that we should reach the top speed in the shortest time possible. In other words, the co-efficient of rise in the acceleration curve (*i. e.*, the gain in speed per second) must be very high. Now, we would doubtless find, by comparing the two integral curves at a point somewhere about 40 seconds from the start, that the alternating current motor would be several seconds behind the other for the same distance. This means that every time we start to go up to a certain speed we are losing a certain number of seconds—5, 10, 15, or whatever the difference is between the two integral curves for the same distance. Now, it is a question whether the conditions of service are such that one can afford to lose those seconds. One can afford to lose them in a case where the schedule speed is not too high; but where everything counts, where it is absolutely necessary to save every second in order to cover the distance and give the people who are to patronize the road a service

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of such rapidity and regularity that it will be attractive to them —under those conditions the alternating current motor is "out of the running." The higher the schedule speed at which the comparison is made, the more hopeless is the case of the a. c. motor.

In closing, I would state for the information of Prof. Gillon, that the motors to which I referred as giving a very large starting torque are not of special construction but are of regular standard manufacture. It is not unusual to see a motor, say of about 100 or 150 h.p. geared for 30, 40 or 50 miles, giving a traction of between 2,000 and 4,000 pounds, while the running traction at full speed would be something between 300 and 600; and we can see, as the curves of tractive effort which are published by the manufacturers for these various motors readily show, that it is possible to obtain a very large starting torque. The curves of acceleration built from these data are usually such as to enable one to obtain acceleration at a much higher rate than is deemed safe and practicable. It is perfectly practicable to obtain estimates, that is so far as motors are concerned, for 200 pounds per ton, net, while it is scarcely wise to do it, a lower figure being usually quite sufficient for most purposes. But I have not heard of any case yet where an alternating current motor can show a rate of rise, that is a rate of acceleration which is at all comparable. (The acceleration curve for the a. c. motor in Fig. 2 indicates a net pull of only about half this amount).

MR. STILLWELL :—Mr. President, I have listened with a great deal of interest to the discussion of Mr. Berg's paper, and to the concluding paragraphs of the paper itself. I am sorry I was not here in time to hear Mr. Armstrong's paper, but I shall read that also with much interest. The subject is certainly a very timely one at present. We are putting in railways in the cities and throughout the country, using the direct current, we are extending cross country lines considerable distances, but we have been going ahead on the old lines of established practice, and I am disposed to think that we have not sufficiently, in the last three or four years at least, studied the possibilities of the alternating current in traction work. I think Mr. Berg's paper adds valuable information upon this very pertinent subject. It seems to me, in a subject so broad as this, it is rather unprofitable to discuss it in a sort of general way. There are so many kinds of traction. It focuses ideas if you consider one of the several kinds of traction or of apparatus at a time. The problem of interurban traffic is a very different thing from the problem of traffic in a large city, running with four, five or six car trains, on one minute headway, and it is also a different problem from ordinary street railway practice. As has been stated, the direct current motor has worked out very well in street railway practice, and probably it will permanently survive in that field. When you come to apply it to a road 50 miles long the condi-

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tions are different, and we certainly ought to investigate the possibilities of the polyphase alternating current. My feeling is that on interurban roads, where the stops are not frequent, where the speed must be high, the alternating current motor has a field that it will one day occupy. To my mind, one of the great objections to using a power plant with sub-stations to supply direct current to a trolley or third-rail has not been stated, and that objection is the old one of the attendance. You are depending upon three, or four, or five points of supply, and at each of those points you must have attendants upon whose intelligence and vigilance you are compelled to rely for a supply of power. Now, if we could substitute an alternating current system with alternating feeders from one central source of supply, we could concentrate our skill at that one point with better results. There is another limitation of the sub-station plan which comes up very forcibly in large railway work in cities, and that is, in this fact, that you are compelled, if you have half a dozen sub-stations, to have a reserve of machinery in each of those sub-stations. The result is your investment in transforming machinery is out of proportion to the investment in generating machinery. I have in mind a specific case which I have had occasion to figure upon in this respect, that of the Manhattan Railway Company of New York, where the installation will consist of seven 5,000 k. w. alternators to take care of the maximum load, and one for reserve. When you come to the sub-stations, with seven sub-stations the equipment will consist of twenty-six 1,500 k. w. converters, with seven additional for reserve. Now, that figures out a total of 40,000 k. w. capacity installed in the power plant, and 49,500 in the sub-stations.

With regard to acceleration, it is unquestionably desirable in the elevated or underground service of large cities to use high acceleration. This is practically imperative in order to secure maximum speed, and consequently maximum passenger carrying capacity; but there are limitations as regards practical acceleration, especially when the power is supplied through sub-stations, in which case the fluctuating overloads upon sub-station apparatus must be considered. These fluctuating overloads from a large number of machines tend to equalize themselves at the power house, so that the fluctuation there is perhaps only 20 per cent. above normal, but in the sub-stations the fluctuations are relatively much greater.

I have calculated some cases of eight car express trains, running on two minutes headway, where it would seem that the increase of load on rotary converters in a sub station may amount to as much as 10,000 h. p. in three seconds; now, that is rolling mill practice. Could we use alternating current motors for traction, eliminating the sub-stations, we should avoid this difficulty, which is a serious one in the case of the converter system,

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but alternating current for traction purposes must be worked out first under the conditions to which it is best adapted, *i. e.*, cross country work, and I very much hope that the experiments recently undertaken in Germany will throw light upon this very interesting subject.

There is a sufficient reason why no very strong effort to use alternating current motors in the rapid transit service of large cities has been made recently in America, and this reason is obvious if we consider what would be accomplished practically upon the assumption that the alternating current motor could be developed satisfactorily for this kind of work.

The operating expenses of elevated railways in America vary between extremely wide limits, but it is safe to say that the average result is not better than 60 per cent. of the gross receipts. The power bill is about 30 per cent. of the operating expenses, or 18 per cent. of the gross receipts. If we use the rotary converter sub-station plan on a large scale, it is not difficult to get an efficiency of at least 80 per cent. from engine to motor. Now, suppose it were possible to eliminate the rotary converters, distribute at 11,000 volts from a central power house to a few sub-stations, there reduce the potential to, say, 3,000 volts, and then operate your motors at 3,000 volts. With efficiency equal to that of direct current motors, you might possibly raise your system from engine to motor to something like a maximum of 90 per cent. This is hardly probable, but assuming that it could be realized, your gain would simply amount to a reduction in your operating expenses equivalent to two per cent. of your income. This result is not a sufficient stake to justify an experiment on a large scale.

In my opinion, also, the risk attendant upon the use of 3,000 volts for traction purposes in cities, except possibly in a tunnel, is far more than offset by any gain in efficiency that can be expected to result by using alternating current motors. The advantage of a polyphase motor system that strikes one at first thought, is the large reduction in plant investment, but when you calculate the saving in operating expenses which would result, could all claims for the alternating current be realized, it seems to me evident that the rotary converter system with direct current motors, as it stands to-day, is the only practical one for rapid transit service in large cities, and that the things promised by the other system are not controlling by any means.

MR. ARNOLD:—I think I stated, Mr. President, when I spoke before, that, as an engineer, I probably would not advise others to do what I believe I would do myself, if I were free to act, by being financially responsible for my results. Therefore, Mr. Stillwell's conclusions as to what an engineer should do, if compelled to act, at the present time are very sound, in my judgment. That does not modify my opinion, though, as to what the future will be. My friend, Mr. Mailloux here, was as thor-

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oughly magnetized, as he puts it, at one time, on the subject as I am, and came back from Europe all right. He seems, however, to have listened to the siren voices of some of my friends, and become so enamoured of those curves of his that he has become partly reconverted, and has rotated to the direct current. I think, however, that he must repent as time goes on. I also admit that, for city work, our present street car system for short distances, and the rotary converter sub-station scheme for long distances, are all right up to the present time. I think the conclusion of Mr. Stillwell is, that it is the best up to date. I agree that this is the safest position to take. I do not believe, however, that for long distance roads the present plans are going to hold. It has been stated recently by a prominent railway official that he can pull freight cheaper by electricity than by steam, and he has been operating an electric freight road and passenger road for some five years. I am very much gratified to have that statement made, and by so good an authority. If that statement is true (I confess that it comes as a surprise to me), we are going to pull a good deal of freight and a good many passenger trains by electricity, and, when that time comes, I believe we will pull them with alternating current motors. These curves of Mr. Mailloux do not worry me as much as they once did; I have probably seen hundreds of such curves, had them made in my own office, and watched the peaks on them, much to my dismay, go too high for comfort, and have tried many ways for overcoming the difficulty caused by them. I do not say how this will be done; I only say it must and will be done, by the engineers of some country, and I do not like to see the electrical engineers of this country lie down and admit that the best thing on earth for railway work is the direct current, and that we, therefore, have perfection.[1]

MR. E. P. ROBERTS:—Mr. Stillwell mentions the attendance in sub-stations. I would state that in a recent preliminary investigation, relative to a considerable length of road, we divided the estimate into two parts:

1st—The cost of producing power at the switchboard in the power house, and

2d—The cost of transmission from such point to the d. c. feeder switchboards in the sub-stations, including first cost, depreciation and repairs, and interest, and adding also, for certain reasons, the capitalization of the salaries in the sub-stations. Our transportation charges were, if I recollect correctly, something more than 50 per cent. greater than the cost of producing energy. I would add, however, that the source of power was a very cheap one. Of course, if we could have estimated on static transformers instead of sub-stations, the cost of transportation of energy would be very much reduced.

1 See page 666 for communication made after adjournment.

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Mr. Stillwell also mentioned excessive momentary loads in sub-stations. We have a case where three cars operating at high speed give fluctuations at the d. c. switchboard of from 0 to 1,000 amperes, sometimes exceeding the latter amount. Where there are such tremendous fluctuations, the question of the installation of storage batteries should receive careful consideration.

PRESIDENT STEINMETZ:—The opinion expressed by Mr. Stillwill, I have heard a number of times, that the three-phase induction railway system would offer over the direct current the advantage of a higher transmission efficiency, and with less reserve apparatus and less operating expense; but, more than that, I not only had that opinion, but carried it out in practice by building such an equipment—that was in 1894, seven years ago—and had a very large number of experiments carried out with it. Mr. Armstrong, who has read the paper, has been in charge of this general investigation and experiment. Since that time we have gone over and over these things again, with another equipment, and another equipment, and were willing even to go to the risk of installing, without any commercial profit, and merely to establish the practical experience in commercial operation, the apparatus for a three-phase railway system, not a very large installation, but an installation of moderate size, where the loss, in case of its inferiority to the continuous current system, would not be considered so serious. But upon more careful investigation my opinion always was reversed, and I came to the conclusion that the transmission efficiency of the three-phase system is lower than that of the continuous current, for the reason that the efficiency of the induction motor in service conditions is so very much lower than that of the continuous current series motor, that the loss in the motor more than makes up for the lesser loss in the transmission line and for the continuous loss in the converter.

Then there is another question that has been spoken of, the enormous fluctuations of load in the sub-stations. Now, if you go to the three-phase induction motor these fluctuatons of load are very much larger, much more intensified, because these fluctuations are due to starting at excessive torque, and the torque increases with the current at a much faster rate with a continuous current series motor than with the induction motor, so that by using the three-phase motor and getting rid of the converter the fluctuations are very greatly intensified. If you could get rid of the static transformer and use only the converter, then it would be all right, because the converter is the piece of apparatus which is least affected by these fluctuations. It will run all right if the load varies 100 or 150 per cent. of a full load. Of all electric apparatus, the stationary transformer is that which stands overloads the least. The objection to overloads, temporary overloads, is the heating of the apparatus. Now, if you take the loss curve of electric apparatus,-the increase of loss with the output, you will

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find that in the stationary transformer it rises at a very much greater rate than in either the converter or the continuous current generator, or the alternating current generator, or the synchronous motor. Only in the induction motor does it rise just as fast. So that you see, the weakest link in the present system is not the converter but the transformer.

As regards reserve machinery, the elimination of the converter in very many cases causes a very much greater reserve capacity, and not only reserve capacity, but reserve capacity continuously in circuit, in the form of stationary transformers. In such a transformer system, to get fair operation, a very small line loss is essential, so that the voltage does not drop much, even with the excessive starting current of the motor. Since the motor torque varies with the square of the current, to get, with a considerable drop in the lines, a sufficient margin of starting torque, such an excessive overload capacity of the motor has to be provided, that under normal running the motor is vastly underloaded, and therefore its efficiency and power factor almost evanescent in service conditions. To avoid this, transformers have to be located at frequent intervals, which means, that frequently the total transformer capacity in such a system is two or three times the generator capacity, more or less. In this case, as in most others, there are certain conditions for which one apparatus is suitable, certain conditions for which the other is suitable; but the higher efficiency of the series motor system is brought out by numerical investigation in almost every case. And then there is the question of attendance. That may appear serious for the first moment, but the rotary converter has been developed to such an extent that it requires extremely little attention. It requires some attention. You have to look at it once a day, or every few days; but you must consider that on these roads you must have stations and ticket agents, and you must have probably, where the speed is very high, a block system, and the men employed there may, every day or so, look at the converter and see whether it has oil in the bearings, etc.; so, as a rule, there is no additional charge for attendance on the rotary converters. Now, all that depends on the circumstances of the individual case. I may add to Mr. Arnold's remarks, that this particular instance mentioned in Mr. Berg's paper, which he criticised, I believe is taken from an actual proposal, and a proposal in which the three-phase and the continuous current systems came into fierce actual competition.

MR. ARNOLD:—I want to ask one question of President Steinmetz. I think I know the case. Why was the alternating bid half a million dollars less than the direct current?

PRESIDENT STEINMETZ:—Well, I don't know why it was. But, you see, sometimes something new—any new apparatus, as a rule, is very much more expensive than an old one; but sometimes it is offered very much cheaper, because people

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do not always realize what they are running into; and while they make allowances for all sorts of things, they may underestimate the allowances. I know of instances of that kind. I have been caught that way myself by making an allowance of 100 per cent. and finding I ought to have allowed 500 per cent.

I would like to hear from some of our English cousins, who come from a country where the question of the relative merits of the alternating and continuous current in railway service has been brought to general attention. I hoped to hear from them before in this discussion, and we should like to hear from them now.

MR. A. H. POTT:-Mr. President and Gentlemen: I am sorry that although I come from a country in which this question has been debated very hotly of late, I can add nothing to the discussion of any value. We at present are looking into the question, both on the continent, in Germany, Austria and on this side, to see what we can learn. At present, so far as I can make out, there are such diverse opinions on both sides of the water as to the merits of this system that I think the best we can do is to shut our mouths until we find from actual practice which is the right solution. The Italian railway, I understand, started yesterday, or a few days ago, and perhaps that will give us some information. But, of course, there is a very strong feeling at present in England that we want something which, for large schemes, is at least cheaper and more elastic than the present systems. I can only say that of the bids which were made in connection with what I suppose is in the minds of all—our underground railway—the bid was very much lower for the alternating system than any other. I mean not just low enough to show a slight difference, but enough to catch the eye of any engineer. That being so, it was only right to look into the matter very carefully. I had hoped to see a very satisfactory demonstration of the high tension alternating system, but I regret to say the financial conditions of the line have led to the railway passing into other hands, and I am afraid we shall see it done by one of the existing methods after all.

MR. SCOTT:—Mr. President, in the very interesting and able papers which we have heard, we have, I presume, not merely the opinion of the individual writers, but rather the concensus of opinion of their colleagues. They have had the facilities of a large manufacturing company, and, as Mr. Steinmetz has just intimated, the efforts and experiments of a large company for several years in this line, and it is presumably the digested result of this work extending over several years by the able engineers of a large company which we have in these papers. It detracts nothing from these papers, and would, I think, only add to them to say that it also confirms the conclusions of other engineers who have been working along the same lines. In fact, within

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the last few months I have prepared a statement somewhat on the line of these papers, and at one time contemplated working it up for this very meeting, but, very fortunately, I have been saved the trouble, as my contribution would probably have added but little to what has already been presented. The conclusions which, in connection with my colleagues of the Westinghouse company, I have arrived at, after having this subject pretty closely in mind for a number of years, are similar to those which have been stated in the papers which have been read. Not only as to general conclusions, but in particular. We, too, have been figuring on some special cases, and some figures have been given which I recognize as very similar to those which we have had under consideration. Mr. Berg's paper takes a specific case and states the premises, the methods and the conclusions. One of his conclusions is that the alternating current motor running in concatenation would take 26 per cent. more energy than the direct current motor. I happen to remember a corresponding figure, which was 24 per cent. The increase of generating capacity (neglecting reserve) which Mr. Berg finds for the alternating, is about 66 per cent. in the generator and about 20 per cent. in the engine. Those figures are within a few per cent. (I do not recall the exact per cent. now) of the conclusions which we reached. This bears also upon another point which was brought up a moment ago, the saving in power by using the alternating current system. The saving in engine power is a negative saving, amounting to about 20 per cent. the wrong way, if our conclusions are right in this particular case. I have not noticed whether in this paper the increased weight of the alternating motors and rheostats was taken into consideration. You took that into consideration?

MR. BERG:—Yes. I think about 65 cent.

MR. SCOTT:—Braking has been referred to in the paper as giving but little advantage in a case of this kind. In general statements which are made with regard to the advantage of employing induction motors, it is stated that if used in concatenation they may be used in braking, thus saving a large amount of energy, theoretically 50 per cent of the stored energy—practically something less than that, possibly 30 per cent. That point was investigated quite carefully. It was found that if the motors are used for braking, they must naturally be worked harder and be of larger size. The consequent increased weight would very nearly compensate for the energy which might be returned. Moreover, on many runs it is feasible to rise quickly to a high speed, drift, and begin working at a low speed, and in that way most of the energy which is stored at the higher speed is returned very efficiently to the service by keeping the car going and overcoming friction. In order to get the greatest advantage in braking, it is necessary to begin braking at the highest speed. The energy which might be returned to the line, in the form of electric

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power, could, therefore, be used in a very much better way by changing the conditions a little, and simply using it for overcoming friction by drifting. The electric braking cannot be done under half speed, and it will in very many cases be possible to drift down to this speed, or even lower.

The concordant results of the two large manufacturing companies that have considered this matter are further substantiated by the results which have been attained by consulting engineers. Take the large roads in New York City, including the Manhattan elevated. The actual result there, after an examination extending over years, in which the matter was fully canvassed by the large manufacturing companies and by the Manhattan Railway Company, led to the use of the direct current motors. That, then, seems to be the American engineering practice for this particular line of work. Foreign engineers have taken the lead in a somewhat different direction. I had the opportunity to read over the abstract of a report which had been made within the last few months regarding the operation of a large road which seems to be in the minds of a number of us, and while I will not attempt to take it up point by point, there are one or two features which I now recall. One was the statement, that the induction motor is superior to the direct current motor, because it does not slow down on grades. It keeps the speed right up grades, and therefore serves to maintain the schedule. My own way of looking at that characteristic of the motor is that it is susceptible of entirely different conclusions. As has been pointed out in the paper which has been read, if we go up grade at the same speed with alternating and direct current motors, then on a level our alternating current motor is limited to practically the same speed, while our direct current motor could run at a much higher speed. It was stated in this report, also, that the weight or cost of the alternating current motor was practically the same. As the American engineers point out, however, in that particular case, it was proposed to have half of the motors on the train idle above half speed, thereby certainly adding to the motor weight. It was proposed also to use motors in braking. We are a little at a loss here to see just what kind of motors are put in competition with direct current motors. It certainly cannot be the kind of motor which has been contemplated in these papers and which we know about over here. In that same report it was stated that a large number of alternating roads in Europe were in operation, the bare statement going without elaboration, and the inference could readily be drawn that all these were of the same class. I think that some of these roads have one car shuttling back and forth, and others have cars going up mountains, neither of which situations would apply to a city road. While it may be hard for us to understand the position of the foreign engineer, the foreign engineer is in a like predicament in regard to us. He is in difficulty to understand just our

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position. I had the good fortune to have a talk on this subject with one of our esteemed foreign visitors a few days ago. After talking a little while, he said that he had really been unable to understand the position of some of the American engineers. He had seen these alternating current roads run, and the cars start, and start quickly, run smoothly, and all that sort of thing, and yet when he had gotten our worthy President at one side and had a talk with him, why, he really seemed to throw cold water on the scheme, and the water seemed, in fact, very cold. He was at a loss to understand why this was. The thing itself seemed to be all right, but he couldn't understand the American engineer. He did the American engineer the compliment not to attribute that lack to his ability, but rather, possibly, to his integrity. He thought possibly it was that, being in connection with a manufacturing concern, the commercial department of that concern repressed the idea, and it was better policy to use the direct current and not make new patterns. I refer to that for one or two reasons. The first thing I did in reply was to resent immediately that position: that opinions given as engineering opinions by a distinguished engineer of a manufacturing company would be so distorted and controlled by the other departments of his company. We hold a reputation as engineers which we want duly respected. In the second place, I think that he is entirely mistaken in assuming that the commercial departments or the management of the larger companies want the alternating system repressed. I think they have put it up to the engineers pretty emphatically, and that it is the engineers, through the results of their tests and investigations, that have retarded the work rather than the opposite. If all this be true then we have a pretty good consensus of American engineering opinion and practice here, where we have been noted for our advanced stand in railway work in other lines, where it was to be expected we would know what is what, and what is best, and be looking out for the best; and the general results should be a pretty weighty argument with those who are taking up the subject. It is true there is now, and there always has been, a sort of feeling that electricity is wonderful, and the alternating current is magic. If you can't do it any other way, the alternating current is the thing that has got to come in and do it somehow. The lesson of the last few days has been that each kind of apparatus has its own legitimate field. There are extremes in conditions where one thing is best and the other will not do, and *vice versa*. A few days ago we considered the alternating current motor and the direct current motor; a little later, the induction motor and the synchronous motor; and to-day, the induction motor for railway work and the direct current for railway work. Now, no one statement will cover the whole ground. There are extremes in which each has its own proper place, and there is a wide middle ground, and our discussions seek to locate the dividing line. Where is the dividing

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line? What are you going to class one way, and what the other? Now, in treating the induction motor and the railway motor, it is not necessary to take into consideration all the peculiarities of alternating apparatus. It is really not a comparison so much between the alternating and the direct current as it is between the two types of working, between the series motor and the shunt motor. If you cannot use a direct current shunt motor with constant field, without varying its field strength, in any particular case, you can depend pretty surely upon it that the induction motor would not do either. The paper under discussion is fortunately quite definite. It is no imaginary and vague statement, but conditions are definitely laid down, and the conclusions drawn are with respect to certain definite kinds of work; and, whatever the future may have in store, I myself am personally quite convinced that the conclusions here drawn with regard to the inapplicability of the induction motor to this class of work are correctly drawn.

The paper will, I am sure, be of great value in giving the results of this kind of work and showing the conditions and the characteristics of this class of apparatus to many of our engineering friends who have not had the facilities for work and investigation in this line.

MR. POTT:—Mr. President and gentlemen, I wish to make a personal explanation, although it may detain you a few minutes. I think that the English cousin referred to by Mr. Scott was myself, and I should be extremely sorry if any American engineer or member of this INSTITUTE thought that I had in any way said anything that was in the slightest degree discourteous to your President. It was quite the last thing I should have said. What I meant when I made those remarks, and I am quite prepared to withdraw it if it is explained to be incorrect, although it was first put into my head by one of your own members, was that in this country, what I think you call the supply business, did to a certain extent control the expressed opinions of the engineers; that is to say, that if the engineers were told they could not get a thing, that was sufficient; for the present they could not get it. But I had no intention whatever of suggesting that any remarks Mr. Steinmetz made in what I termed throwing cold water on the three-phase system, had any reference to his connection with a supply company, and I hope that this is quite clear. I think you will excuse my saying that in almost any country manufacturers are always apt rather to "gas" on things which they are fully prepared to supply to the market than on those things which they are not.

PRESIDENT STEINMETZ:—Gentlemen, regarding the last statement, as the rule the tendency with large companies is rather the opposite, and justly so. While it may be very nice and convenient, especially in hard times, just to build what you have built before, and not experiment, at the same time, for a large

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company, the most serious matter is to be left behind, and it is of first importance, then, always to be leading; and for that reason, if there is any new method, any new problem, that comes up which even faintly promises to offer a prospect of success, it is just the large companies that are willing to investigate it and to put all their energy into finding out exactly what there is in it. Most propositions, however, which appear very encouraging at first, when carefully investigated lose their promising nature, and then very naturally the one who made the proposition is very likely to think that it is only conservatism which opposes the introduction of new, revolutionary ideas; whereas, in reality it is because they are inferior to what exists. For instance, with regard to this very thing, since 1894, when I made the first experiments, I have been trying to install a three-phase railway system, and I have enough influence with the company with which I am connected, that we were willing to give it free of profit, at cost price, if we only could get the three-phase railroad installed in commercial service. In several cases we almost got it, but always at the last the customer concluded after carefully investigating the matter and consulting with us, that really there was no excuse for him to take it, even at cost price, and so we have not been able yet to build any three-phase railroad, except one which we are now building for northern Italy; but still, as has been brought out in our discussion, there are certain conditions of operation which are suitable for the three-phase railroad, and I hope to live long enough to see a railroad equipped under those conditions with three-phase motors; that is, a railroad of some magnitude, not with one or two cars climbing a mountain or shunting to and fro, but a real railroad system installed on the three-phase plan under conditions which are eminently suited for three-phase, and more suitable for three-phase than for direct current.

MR. STILLWELL:—Mr. President, just a word. It has been pointed out that in my remarks a while ago I did not refer to the effect of the motor efficiency upon the efficiency of the system as a whole. I had in mind the efficiency of the motor, assuming that the manufacturers would be able to work out motors which would be regarded of the same approximate efficiency. I was considering simply the question of distribution, which, of course, when you come to constructing, is to be considered as a separate matter. But there is a point with regard to the alternating current motor which is alleged to be a possibility and a practical thing by a very influential and well-informed firm of manufacturers in Europe; that is, they return a very substantial amount of energy to the system. Now, the importance of that depends upon the kind of service you are talking about. For service like that of the Manhattan Railway of New York, or underground, of these Chicago railroads, where you have 60 seconds between stops, or are accelerating

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for 25 seconds, and drifting for perhaps 25 more, and putting on the brakes for ten—the direct current motor is not an ideal or final consummation as we use it. With the conditions of efficiency of the direct current motors with their rheostats it does seem to be a fault that with a third rail, with 86 per cent. of energy to start with from the switch board of our power plant, we have to kill 35 per cent. of that amount before we can get it into the shape of power for traction, the net result being about 50 per cent. of the energy you start with at the switchboard being utilized to draw the train.

I have been very greatly interested in the fact that the representatives of the two manufacturing companies in America who have given most attention to this subject are in close agreement as to the possibilities and limitations of the induction motor. At the same time I wish to express the hope that they are not going to bury that question. It would be a great pity if three years from now, after we have adopted, perhaps, the continuous current system on the New York underground, we should have it pointed out to us that a firm of Buda Pesth had put in in London a system cheaper to install and equally effective and efficient in operation. We must not take that risk.

PRESIDENT STEINMETZ:—Gentlemen, I am sorry to say that this great advantage claimed for the three-phase induction motor, to return energy in concatenation during retardation, is also one of the features which careful numerical investigation does not bear out, for this reason; if you run practically at synchronism until the moment the brakes are put on, that is, if you operate the motor in a manner which is improper and wasteful, you can return energy; but, as Mr. Mailloux has very well brought out, the proper way of operating a motor under rapid transit conditions, that is, the way to carry the motor in a given time over a given distance, with the minimum expenditure of energy, is to accelerate as fast as possible to high speed, then to shut off the power, and coast until it is time to put on the brakes, because thereby you devote to necessary operation a large part of the energy otherwise dissipated in the brakes, and it is naturally more efficient, instead of wasting energy in the brakes, to use it for carrying the train over the friction of the road. Now, in the three-phase induction motor, where the maximum speed is a little below synchronism, and you begin to coast at this speed, at the end of coasting you have fallen down from a little below synchronism by the total energy expended on the friction of the road, and you are fairly close to half speed, and the motor can return energy only above half speed. That means the range over which it can return energy becomes very small, and the actual amount of energy returned in this case under average conditions, even with very short stops, where you cannot coast for a very long time, is a very few per cent., so few that it does not pay commercially to use it, because the energy is returned at the

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expense of an enormous amount of current which passes through the motor and heats it. So the induction motor as an electric brake for returning energy is not suitable for rapid transit work. It is all right to use the motor in concatenation to start and get up to half speed; but even then it is inferior in efficiency to series control of continuous motors. Two concatenated motors are lower in efficiency than two continuous current motors in series, the current of the first motor being in excess. So that even this claimed advantage of the polyphase induction motor in returning energy is not borne out by experience.

MR. STERN:—As to the suggestion of Mr. Stillwell regarding long runs, it appears that there has not been much, if anything, said about running the induction motor for long distances, about 50 miles, for express service, or distances approaching that, say 20, 30 or 40 miles, and it occurs to me that under such conditions as that there might be something said in favor of it. The induction motor appears to have its analogy, in mechanical engineering, in the gas engine. Regarding their relations to torque and speed, the acceleration of both have small values. There are mechanical means, however, as has been stated by Mr. Scott, for varying the torque and the acceleration while the speed of the motor is kept constant, which are employed in the driving gear of gasoline motor vehicles, but on long runs, such as I have just mentioned, it would appear that the motor would take care of that itself, particularly on level roads, and the reference that Mr. Arnold made some time ago to the possibilities of the induction motor for railroad travel on long runs (trunk lines) might have some points of merit, and those points it appears have been overlooked in considering urban and interurban traffic when the issue was one of express service. That is the point I believe Mr. Arnold wished to bring out.

MR. H. C. SPAULDING:—Noting the suggestion that has been made about using mechanical means for obtaining speed variation with constant speed motors, it may be of interest to the members present to note a device which I have had occasion to use more or less in machine design, and have found most efficient for the purpose. Suppose (referring to blackboard sketch) on either the driving or driven shaft, a pulley having a deep V-groove, and split through the bottom of the groove into two parts, one of which is fixed to the shaft, the other being adjustable by any convenient means, so as to vary the distance between the two conical faces thus formed. In this groove is used a narrow, thick beveled edge belt which drives by side contact only, and does not bottom except when it is desirable to combine a starting and stopping function with variable speed—in this case a loose pulley being inserted between the two faces of the groove pulley, which are recessed for the purpose. By using this device on both driving and driven pulleys (the take-up on the latter being

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effected automatically by a spiral spring), a variation of speed between wide limits is obtainable with maximum efficiency, and entire absence of excessive pressure on bearings. At the Columbian Exposition in Chicago I ran something like an average of 15 h. p. from the main shafting by this device, and, while such economy is not to be expected in every case, in this instance only a half horse-power was charged for, as all computations were made by the inspector on a basis of belt width. In this case the belt was 2 inches wide, oak-tanned, with staggered rivets, and I believe a similar mechanism could be used to advantage in solving some traction problems. One application is fully described in United States patent No. 596,281, issued to me on December 28, 1897.

MR. HOLMES:—Mr. President, there was a company that exploited this speed-varying device applied to a car. Some of those present from Chicago may know of it. I have seen drawings of such a car intended for suburban work, but it never went further than the experimental stage.

In electrical engineering, Mr. President, there is a firing line of battle; there are not many of us engineers who are working on that line. The representatives of two or three large manufacturing companies are truly in the battle fray, but most of us are handling problems that are not experimental. I was very much interested, therefore, in the percentage which Mr. Stillwell gave, showing the deterioration of machinery in the Cataract plant. Here is a great hydraulic electric plant, in fact, the pioneer in this country, which has been running for eight years. He tells us that the cost of electrical repairs on it is less than two per cent. If I recollect rightly, this is less than half the cost of repair upon its hydraulic machinery. Coming down, then, to the alternating station, where electricity is used in its various forms, we find the apparatus there, also, of lasting quality and extremely satisfactory. Now, is it not plain to us that the revolving field, alternating current generator, therefore, with the efficiency which it now has, is a thing that we can recommend permanently as a machine which does represent the final thing along the lines of electric generation of power with magnetism and electricity? It seems to me that it does. I, therefore, have pictured to myself the problem which is sometimes stated: If, for instance, between New York and Albany, you divide the distance, or travel half the distance, and then travel, or divide the distance again, and then divide it again, how long will it take you to reach Albany? Practically infinity. But in this development of the three-phase alternating generator and its connections, have we not got very far along toward Albany, and can't our recommendations to people who wish to buy be made with great confidence? It does not seem to me as if the alternating current generator will become obsolete in the life of this generation, and it seems to me as if its lasting quality is assured. I was also

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interested in the statement concerning the Falls plant, that if they were building over again, or were building *de novo*, the apparatus which they would put in would not secure a saving of more than $1 per kilowatt a year. That is something very interesting, considering the fact that this problem was proposed eight years ago.

MR. STERN :—I do not think that is very encouraging to engineers, Mr. President. If we were to stop where we are and continue building the same machinery that we are building, engineers would not have very much to do in the future.

MR. MAILLOUX :—Mr. President, I think that before this discussion ends some allusion ought to be made to another phase of the electric traction problem which, though not specifically mentioned in the paper, is none the less one of the most important factors in the problem now before us. I think that an occasion of this kind is suited to bring to the attention of the profession some of the points on which we are still in the dark. One of the things on which we most need information, at present, is data relating to the effect of the air and the wind on the resistance of trains. Ten years ago it was a matter of little consequence, because the speeds at which we ran cars were so low that the wind friction was a negligible quantity. The greater portion of the energy expended in propelling a car at full speed; in fact, nearly the whole of the energy was expended in overcoming the friction of the bearings; but to-day, when the speeds have reached 30, 40, 50, 60 miles, and when speeds of 100 miles or more per hour are contemplated we are reaching a condition when the rolling friction of the train becomes the negligible quantity in its relation to the air friction. It seems rather strange at first blush to think that in a train running at 65 miles an hour, more than two-thirds of the energy is expended in a rubbing of some form or other against the cars of the train, yet it is a fact. We are, unfortunately, almost unprovided with data on this question, although these data are destined to have a great influence on the solution of many problems. The absence of these data is responsible to-day for the fact that we can only give approximate solutions and approximate results of calculations, as given, for instance, in the curves, in the valuable paper of Mr. Berg. The curves relating to drifting or coasting, are all straight lines, whereas we know that they cannot be straight lines. The curves of acceleration must be concave, while the curves of drifting must be convex, to the axis of x; yet we have no means of determining definitely and precisely in what manner the departure from the straight line exists. In some cases, especially at the higher speeds, that departure is so great as to become of the highest importance indeed in the result. I have seen instances lately of speed-time curves which were made on the assumption that the train friction was a constant,—12, 13, 15 pounds per ton, for instance. These curves might be correct enough if the speeds remained under 15

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or 20 miles per hour ; yet when the maximum speeds run up to 30 or 50 miles per hour this assumption is far from true, for the train friction would run up to 25 or even 30 pounds. Under such conditions you can readily see that the curves are hypothetical and are only a rough approximation, and unless the motors have a great deal of margin in capacity for starting current, unless it be possible to raise the potential of the line or in some other way to get higher speed, conditions might arise in which the theoretical schedule could not be made when it came to actual practice. Now, in order to solve this problem, and like problems, it would be necessary to have data, and data, and data of all kinds, from all sources and under all conditions, and it is especially to the engineers who are designing and installing traction plants of all kinds that I wish to appeal. I think that efforts should be made by all engineers to procure and collate data on this subject of train resistance; it does not make much difference under what conditions, provided the conditions are noted. It will be necessary, of course, to sift out the data; but if the data themselves were only available there are many engineers who are competent to do the sifting, and who would be only too glad to do so. In that way we could eventually arrive at some definite, accurate information that would be of the greatest value. Efforts have already been made by engineers, but they have been isolated to some extent. It is very desirable, indeed, that a sort of joint effort should be made by all engineers who have the opportunity in connection with the plants in which they may be interested, as supervising, constructing or operating engineers, to procure and make supplemental data. I will here state that I am greatly indebted to the General Electric Company for some data on train resistance at high speeds, which they themselves have obtained in a particular case. These data turned out to be of extreme utility to me; and while they apply only to this case, or to cognate cases, yet but for these data, I would have been almost entirely in the dark as to the assumptions that one should make in regard to the effect of wind resistance at high speeds; and I assure you, gentlemen, that we are likely to hit far off the target if we have not some means of guidance in making assumptions in such matters. It is for that reason that I deem the matter of so great importance, and I think it ought to have proper and systematic attention. One of the mooted questions at present among engineers is whether the wind pressure causes expenditure or loss of energy by the boring effect of the train, or by the skin friction of the sides of the train. I had a very interesting conversation with our colleague from Belgium, Prof. Gillon, the other day on the subject, in which he related the conclusions of the German engineers, and I think it would be quite interesting if Prof. Gillon would state something further in regard to the concensus of opinion of continental engineers on that question.

MR. ARNOLD :—Mr. President, pending the collection of such

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data as Mr. Mailloux proposes, I suggest a simple formula which I learned some years ago, and which, I believe, was proposed by the *Engineering News*, after quite a prolonged discussion of this subject in its columns by its readers. It is: $R = \frac{1}{4} V + 2$, where R equals the total train resistance in pounds per ton and V equals the velocity in miles per hour, while 2 is a constant determined by experiment.

This is short and sufficiently accurate for practical purposes for speeds up to 50 miles per hour.

MR. MAILLOUX:—Mr. President, I submit that the rule is over 100 per cent. out of the way at 50 miles per hour.

MR. ARNOLD:—I submit, Mr. President, that I do not think it can be proved so far incorrect at or under the speeds to which I have limited it.

MR. MAILLOUX:—The rule is at least 100 per cent. out of the way, perhaps 200, at 60 miles.

PROF. GILLON:—[*Translation*] What I have said to Mr. Mailloux is a mere expression of opinion. In my opinion, that which plays the essential role in the resistance which the air opposes to a moving train vehicle is the friction of the air against the walls of the vehicle. If this be true, the nature of this wall and the care that should be taken in making it as smooth as possible would assume great importance. On the other hand, the sharpened form sometimes given to the front end of high speed cars would become merely accessory, and it would seem to be preferable, if the above hypotheses be true, to utilize this space in the front of the car for the motorman compartment.

It may be questioned that if we should allow the wind to blow through the trucks and motors beyond the extent required for ventilation, whether it would not be better to cover the parts below the vehicle, so as to reduce the wind resistance. These are questions which experience alone can answer, and of which we can hope for a solution as soon as there are high speed electric trains in operation.

MR. E. P. ROBERTS:—Mr. President, early in the discussion you made a statement that sub-stations could sometimes be placed in towns where a ticket and baggage agent could also look after the machinery, and I noticed that several smiled as if this were not a practical proposition. In our experience, it is a matter which should always be taken into consideration, as, for example, in one road which we designed it was a question whether to place two sub-stations in the country, one each side of a town, in which town it was also decided to have a ticket, baggage and freight agent, or whether to place a sub-station in the town. Although the latter somewhat increased the first cost, the increase was mainly due to the increased feeder wire, which has practically no depreciation and repair account, and the cost of the machinery was actually less; and, capitalizing the differences in salaries, the result was materially in favor of the one sub-station, even though

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the resulting distance between the sub-stations was in excess of what would ordinarily be considered good practice.

PRESIDENT STEINMETZ:—If there are no further questions, I will call upon Mr. Armstrong and Mr. Berg to conclude the discussion.

MR. BERG:—After Mr. Scott's discussion of my paper, there is nothing I have to say particularly. I would only like to explain to Mr. Mailloux, that in calculating these curves I very carefully took the variation in resistance into consideration at first, and afterward drew the curves on the basis of average resistance during acceleration. I found the amount of departure, I think, one per cent., and I thought to save all discussion I would simply draw a straight line, as the difference was so small it was impossible to detect it. Regarding the distance-time curve, when calculating that curve, I actually put in dots and dashes for two curves, but afterward drew one line, because they came so close together in this particular scale that if I tried to draw two curves they would have been so close the difference would hardly be noticeable. Had the maximum speed, however, been say twice as high, Mr. Mailloux's arguments might well apply.

MR. ARMSTRONG:—Mr. President, I think it is an extreme disappointment to several of the members here that the induction motor has not proved itself worthy of installation in some of our more important plants, and the person more disappointed than any other, I believe, is our President. You can make very beautiful curves in induction motor calculations, and to the mathematician, especially, it is a source of delight, and for that reason more than any other I think our President is seriously discouraged at the failure of the induction motor to prove itself worthy of more careful consideration. It has been brought out by the discussion to-day that the induction motor is unsuitable for city traffic, rapid transit work, elevated work, or, in fact, any class of service where the stops are at all frequent. Without going into the details of what has been said, I would add simply that I agree with them thoroughly, but I would like to point out that rapid transit work is not confined to city limits. On the suburban roads, although they may have distances of two or three miles between stops, the schedule speeds may be so high that they constitute another class of rapid transit roads; the conditions governing distribution, and, in fact, of the system as a whole, are very nearly those governing the city roads, which are classed as true rapid transit roads. The cars are continually accelerating, they drift, and brakes are applied, very similarly to the way it is done in city work, except that the intervals are longer. And, therefore, in bringing out many of the statements in my paper, I had in mind that interurban roads and suburban roads, and more especially those of the future, called for such extreme qualifications of the motors that the induction motor is not at all suited for the work.

MR. N. C. SAWERS:—Mr. President and Members of the AMERICAN

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INSTITUTE OF ELECTRICAL ENGINEEES :—I want to take this opportunity before adjournment to thank you all very much indeed for your great kindness and most generous hospitality to us during our visit here. Our visit will always be a most pleasant recollection to all of us, and the next time you come to England—and I trust that day is not far distant—although we cannot promise to provide such sumptuous intellectual fare as we have enjoyed here, still I hope you will be able to pick up some titbits here and there, and, from the social point of view, enjoy yourselves as heartily and meet as thoroughly good fellows in our little country as we have in your big one.

PRESIDENT STEINMETZ :—Gentlemen, I think I voice your sentiments when I say that we have not the least doubt that when we go over the great pond to our cousins on the other side, we shall be received as well as is imaginable and shall have a very nice time; and I hope that we shall once in the future meet over there again and enjoy ourselves just as well as is possible.

Mr. Pope, our Secretary, desires to make some more announcements.

SECRETARY POPE:—This will be very brief, gentlemen. I have a telegram from Mr. Stanley, of Great Barrington, Mass., in which he requests that the INSTITUTE be invited to visit Great Barrington next year on the occasion of its Annual Convention. This matter has been considered by some of our members, and I can say, from personal knowledge of the ground and the facilities, that it offers every advantage for a very successful and pleasant convention, and I hope in due time the Board of Directors will take it into consideration.

PRESIDENT STEINMETZ :—The program of our Convention is herewith closed, and I thank you very much for your very generous attendance on the meetings and for the interest and participation you have shown in the discussions, which I feel confident have made this Convention one of the best we ever had. As regards attendance, it certainly has been, and even as regards social entertainment, I believe we have not lagged behind previous Conventions, although unavoidably some of the surroundings have not been quite as appropriate as we could have desired.

I believe a motion to adjourn the Convention is now in order.

On motion of Mr. Hering, seconded by Mr. Arnold, the meeting adjourned.

[CONTRIBUTED AFTER ADJOURNMENT BY C. O. MAILLOUX.]

In my previous discussion of Mr. Berg's paper, in referring to the diagram at the top of Fig. 2 of his diagrams, I stated that if the distance curves for the a. c. motor and for the d. c. motor had both been plotted together, it would be found that these distance curves do not coincide at all points, but show a percep-

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tible time interval between them at certain points. The accompanying diagrams, Figs. A and B, prove that this is actually the case. These diagrams have been prepared by means of an integraph, an instrument which not only computes, but actually draws the integral curve. The two curved lines in each diagram represent the two integral curves corresponding, respectively, to the a. c. and the d. c. motors, exactly as they were drawn by the integraph when the tracing point of the instrument was run successively over the two speed-time curves, namely, the one for the a. c. motor and the one for the d. c. motor, shown on Fig. 2 of Mr. Berg's paper. In Fig. A the setting of the instrument was such as to preserve and reproduce exactly the same scale for both the ordinates (distance traversed in feet), and the abscissæ (time in seconds). In Fig. B the scale of abscissæ is also the same as in Mr. Berg's diagram, but the scale of ordinates has been purposely magnified to a little over twice the scale of ordin-

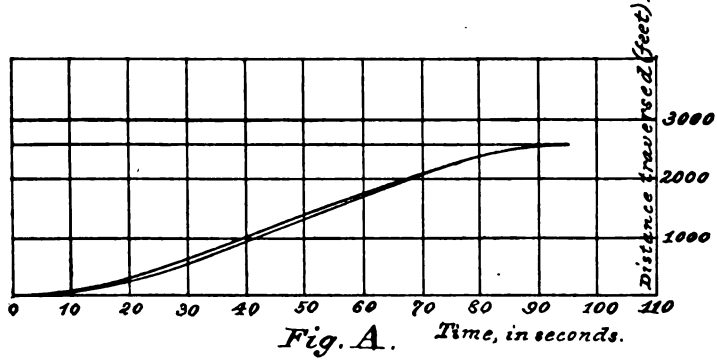

Fig. A.

ates in Fig. A. In both figures the lower line of the curve is the integral or distance curve corresponding to the a. c. motor, and the upper curve is that corresponding to the d. c. motor. It is seen that in each diagram both curves reach the same height (corresponding to a little over 2,500 feet) at the end of the run, in the same time (about 95 seconds), showing that the a. c. and d. c. speed-time curves as drawn in Mr. Berg's diagram (Fig. 2), are really curves of equal area, as intended by Mr. Berg. The divergence between the lines shows that the d c. motor (upper line) during the middle part of the run reaches a given point; that is to say, runs over a given distance a little sooner than the a. c. motor, being about 2.5 seconds ahead at the point of maximum divergence. The actual time interval or difference is the same in both diagrams, but is more plainly visible in Fig. B, owing to the enlarged scale of ordinates.

As may be inferred from my previous discussion, this divergence would be still greater if an attempt had been made to accel-

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erate faster in both cases, the rate of acceleration being quite low for both motors, in Fig. 2 of Mr. Berg's diagrams, thereby favoring the a. c. motor.

During the first 20 seconds, or for the portion of time during which the acceleration line is straight for both motors, the mean acceleration in Fig. 2 is about 0.8 of a mile per hour per second for the a. c. motor, and quite nearly, but a trifle under, *one* mile per hour per second for the d. c. motor. It would be found that the acceleration in the case of the a. c. motor can only with great

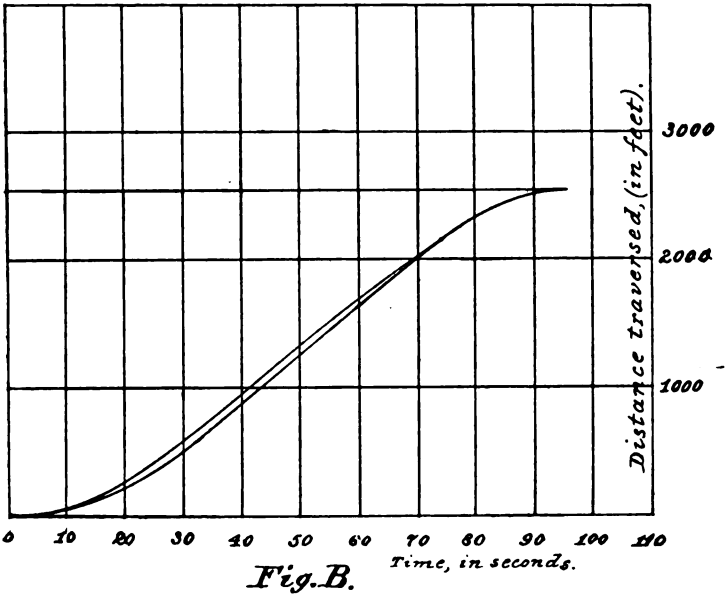

Fig. B.

difficulty be made to exceed 1.5 miles per hour per second, while it is not at all difficult to attain an acceleration of at least 2.5 miles per hour per second with the d. c. motor, if desired. For a rapid transit system having relatively short runs and a high schedule speed, and, therefore, requiring a maximum speed of say 50 or 60 miles (instead of about 27, as in Mr. Berg's diagram), a very great divergence would necessarily result between the distance curves corresponding to an a. c. motor equipment and a d. c. motor equipment for the same service, for the reason that the mean acceleration in the case of the d. c. motor would be equivalent to about two miles per hour per second, as against about 1.4, or possibly, 1.5 miles per hour per second, which is practically the present limit for the a. c. motor.

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[COMMUNICATED AFTER ADJOURNMENT BY B. J. ARNOLD.]

During the discussion I was unable, on account of certain causes, to give fully my reasons for believing in the ultimate supremacy of the alternating current motor for railway work, so I would like to supplement my remarks somewhat.

It is well known among those who have to do with electric railways that we have just about reached the limit of train weight if we must confine ourselves to the present accepted maximum direct current voltage of 650 to 700 volts. Beyond this the commutator and insulation difficulties with the direct current motor seem to be too great to overcome. If confined to this limited voltage, the quantity of current necessary to haul a heavy train becomes so large that no single contact shoe or wheel is capable of properly taking it off the working conductor without excessive heating. This necessitates the multiplication of contact points or shoes, which in time become prohibitive if the working conductor is placed overhead, and if the working conductor is placed near the ground, as is usual with the present third rail system, the voltage must necessarily be kept low on account of our inability to completely insulate it. The low pressure on the working conductor necessitates large first cost in the distributing system, which, in my judgment, is at present excessive, and must be largely eliminated before we can hope to handle heavy railroad work commercially successful by electric propulsion.

With the alternating current motor, the working conductor can be placed high enough to properly insulate it, and energy transmitted over it at any desired potential which may be high enough to permit sufficient energy being taken off on a single contact point to propel a heavy train and keep the quantity of current low enough to make its heating effect negligible.

The present contended lack of efficiency and low rate of acceleration charged against the alternating current motor are, in my judgment, less objectionable and more easily overcome than the objections I have pointed out.

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[Discussion of President Steinmetz's Paper on "Oscillations of Extremely High Potentials in Alternating High Potential Transmissions."—Communicated after Adjournment by Percy H. Thomas.]

[See p. 383 for Mr. Steinmetz's paper.]

Mr. Steinmetz has presented a very interesting paper, and, as a result of his investigation, has reached some rather unexpected conclusions. The third of these conclusions, which are summarized at the end of the paper, is particularly unexpected. It is this portion of the paper which I wish to discuss. If it be true that a short circuit may cause a rise of potential beyond the strength of available insulating materials, the matter is of great importance and deserves the most careful consideration. The basis from which the author arrives at this conclusion is equation (39) of his paper. I do not consider all the assumptions made in the derivation of this equation to be justifiable, as I will explain.

The differential equation (3), which is the mathematical basis of the whole paper, expresses the fact that in the circuit under discussion the instantaneous value of the impressed e. m. f. always equals the sum of the ohmic drop, the back e. m. f. due to self induction, and the e. m. f. on the condenser. The potential on the condenser has previously been expressed as the integral of the current flowing in the circuit divided by the capacity; that is, the current considered in the equation is the charging current to the condenser. The differential equation evidently applies to the phenomena of charging a condenser through a circuit containing inductance and resistance. The author derives from it a general equation for the current in the circuit and e. m. f. on the condenser. The solution of this problem has been given by others as well, for example by Bedell and Crehore in their book, "Alternating Currents." They start with practically the same differential equation and derive a result (see page 127, equation 181) the equivalent of equation (13) in Mr. Steinmetz's paper. In equation (35), preparatory to deriving equation (39), the author substitutes for the initial current of his general equation the current flowing in the circuit on a short circuit across the lines at the condenser. This substitution is justifiable only on the assumption, which the author directly makes, that the short circuit current is instantaneously interrupted at the point of short circuit and that no diminution in the strength of the current in the rest of the circuit occurs at the time of this interruption. This assumption, which is the step in the investigation that I do not consider justifiable and from which results directly the great rise of potential of equation (39), is certainly not in accordance with actual conditions in transmission circuits. For not only do such short circuits fail to open instantaneously, but when accompanied by an arc the current strength is considerably limited before breaking by the resistance of the arc. Also any excessive rise of potential will cause the short circuit to be re-established at the original point. Furthermore, if a similar assumption of a sudden interruption of the current is made in any electric circuit containing inductance, a rise of potential will result.

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The rise of potential derived from equation (39) is the well known phenomena of a high potential resulting from the sudden stoppage of current in a circuit which includes inductance. That is, when the short circuit occurs, energy is stored in the inductance of the transmission line by the short circuit current and on the assumption of the instantaneous rupture of the current, the energy can be discharged only into the condenser, which of course means a rise of potential depending on the amount of energy stored and the capacity of the condenser. In fact, the expression $\sqrt{k/x}\,E$ which the author gives as a mathematical expression of the extreme rise of potential under discussion, may be directly derived, algebraically, without the use of a differential equation, provided the same assumptions are made as in the paper. For, in a circuit of inductance L, in which a current i_0 is flowing, the energy stored in virtue of the inductance is $1/2\ L\ i_0^2$. If the assumption is made that the current i_0 which is taken to be the short circuit current, is instantaneously interrupted at short circuit this current can discharge only into the condenser, which, must therefore, receive the full amount of this energy. The energy stored in a condenser equals $1/2\ CV^2$ where V is its potential. Equating these two quantities and solving for V, we have the equation $V = i_0\ \sqrt{L/C}$; or substituting for C its value from the paper,

$$\frac{1}{2\,\pi\,N\,k} \text{ and for } L \text{ its value } \frac{x}{2\,\pi\,N},$$

we have $V = i_0\ \sqrt{x\,k}$

Again making the assumption as in the paper, that $r = 0$, $i_0 = E/x$, therefore $V = \sqrt{k/x}\,.\,E = e$, the result given by the author. That is, by obtaining the value by which the potential of the condenser must be raised to contain the energy stored in the inductance of the circuit, we get the author's expression for the rise of potential under discussion.

The fact that the rise of potential results from the author's assumption of his initial conditions may be shown by placing $E=0$ in his general equation (17), for the voltage on the condenser that is, by assuming that no external electromotive force is applied to the circuit after the time, $t=0$. By his assumption, $e_0=0$ in the case of a short circuit. Making $e_0=0$ and $E=0$ all terms vanish except the term

$$\varepsilon^{-(r/2x)\phi}\left[\frac{r^2+q^2}{2\,q}\right] i_0 \sin\frac{q}{2\,x}\varphi = \varepsilon^{-(r/2x)\phi}\,\frac{4\,k\,x}{2\,q}\,i_0 \sin\frac{q}{2\,x}\varphi$$

Making the assumption again that $r = 0$, we have $i_0\ \sqrt{k\,x} \sin \sqrt{k/x}\,\varphi$, and for the maximum potential as before $i_0\ \sqrt{k\,x}$, or substituting the old value for i_0 we have $\sqrt{k/x}\,.E$. That is, the

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same maximum rise of potential is obtained if we have no applied e. m. f. in the circuit after the time of rupture of the short circuit. This shows that the assumption of his initial current i_0 introduces the critical term.

Returning to the third conclusion of paper, we see that the rise of potential depends directly on the assumption of a sudden break of the short circuit current. Therefore, anything that tends to render the opening of the short circuit more sudden will increase the danger of an excessive rise of potential That is, in the absence of direct experimental evidence to the contrary from actual transmission circuits or their equivalent, the assumption will naturally follow that these types of circuit opening devices, which have special forms for getting a quick break—for example, magnetic blow-outs, explosive types, air blasts or breaks under oil—are more likely to cause a dangerous rise of potential than the open air type.

In conclusion, I may state that this paper is an interesting and important contribution to the subject of switching in high tension circuits. Unfortunately the mathematical treatment can show nothing as to the vital question as to how sudden a break may result from the various types of switches and circuit breakers. Also the fact should be recognized, which is not directly stated in the paper, that the expression obtained, apparently showing the possibility of an extreme rise of potential, is not due to a new or mysterious principle, but is a particular case of a well known principle in electrical work.

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Associates elected at a meeting of the Board of Directors, held Friday, June 28th, 1901.

ASHE, SYDNEY WHITMORE	Assistant in Physics, Polytechnic Institute; residence, Webster Avenue, Bedford Park, Brooklyn, N. Y.	Samuel Sheldon. Wm. J Hammer. Ralph W. Pope.
BAKER, WILLIAM EDGAR	Chief Electrical Engineer, Manhattan Railway Co., 32 Park Place, New York, N. Y.	W. B. Potter. Henry G. Stott. E. W. Rice, Jr.
BAUSCH, FREDERICK EMIL	Chief Engineer, Pittsburg Plate Glass Co., Crystal City, Mo.	E. L. Nichols. H. A. Wagner. H. J. Ryan.
BICKNELL, DANA EDWIN	Assistant in Inspection Department, Western Electric Co., 57 Bethune St; residence, 2 Perry St., New York, N. Y.	Geo. A. Hamilton. H. F. Albright. G. F. Atwood.
BRIESEN, HAROLD V.	Student in Electrical Engineering, Columbia University, N. Y.; residence, 80 Hackensack Ave., Hoboken, N. J.	F. B. Crocker. F. Townsend. M. I. Pupin.
BROWN, BENJAMIN	Student, Polytechnic Institute, residence, 381 Sackett Street, Brooklyn, N. Y.	Samuel Sheldon. Wm. J. Hammer. Ralph W. Pope.
COLLINS, ARCHIE FREDERICK	Electrical Engineer and Inventor, Collin's Wireless Telephone and Telegraph Co., 132 S. 6th St, Philadelphia; residence, Narberth, Pa.	H. W. Blake. T. C. Martin. W. D. Weaver.
GILMAN, FRANCIS LYMAN	Telephone Engineer, Western Electric Co., 463 West Street; residence, 132 East 16th St., New York, N. Y.	O. A. Bell. P. G. Burton. G. F. Atwood.
HALL, HARRIOTT CURTIS	Glen Cove, L. I. Student, Polytechnic Institute, Brooklyn, N. Y.	Samuel Sheldon. Wm. J. Hammer. Ralph W. Pope.
LOBO, GUSTAVE	Office Engineer, V. M Braschi & Bro., Apartado No. 830, Mexico City, Mexico.	F. B. Crocker. T. C. Martin. Wm. J. Hammer.
MACCALLA, CLIFFORD SHERRON	Foreman Construction, Edison Electric Illuminating Co., 360 Pearl St.; residence, 11 St. James Pl., B'klyn, N.Y.	W. S. Franklin. W. S. Barstow. H. A. Lardner.
MASON, HOBART	Graduate Student, Polytechnic Institute; residence, 432 Greene Ave., Brooklyn, N. Y.	Samuel Sheldon. Wm. J. Hammer. Ralph W. Pope.
MCCARTY, FRANCIS ALEXANDER	Electrical Engineer, Noyes Bros., 31 O'Connell St., Sydney, Australia.	Chas. F. Scott. C. E. Skinner. W. K. Dunlap.
PITCHER, FRANK HENRY	Chief Engineer, Montreal Water and Power Co., 62 Imperial Building, Montreal, P. Q.	R. B. Owens. L. A. Herdt. R. T. Lozier.
SCHROEDER, HENRY	Inspector, Edison Electric Illuminating Co.; residence, 137 Madison Ave., New York, N.Y.	Arthur Williams. Douglass Burnett. Warren D. Brown

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SONN, GEORGE C.	Professor of Physics, Newark High School; residence, 285 Belleville Ave., Newark, N. J.	Ralph W. Pope. Wm. J. Hammer. F. E. Kinsman.
STEVENS, CABOT	Electrical Engineer, Brooklyn Edison Electric Illuminating Co., 360 Pearl St.; residence, 11 St. James Pl., Brooklyn, N. Y.	W. S. Barstow. W. L. R. Emmet. Calvin W. Rice.
THAYER, WM. CURTIS	Draughtsman, The Natural Food Co., 11 B. St., Echota, Niagara Falls, N. Y.	Chas. F. Brush. C. A. Adams. E. A. Deeds.
WILSON, ROBERT LEE	Constructing Engineer, Westinghouse Electric and M'f'g. Co., residence, 95 Clark Street, Brooklyn, N. Y.	W. S. Barstow. Chas. F. Scott. W. K. Dunlap.
WOLFE, JOSEPH THOMAS	General Engineer and Sales Agent, Noyes Bros., 15 Queen St., Melbourne, Victoria.	Chas. F. Scott. A. J. Wurts. J. S. Peck.
WOODWARD, FREDERICK SEARLE	Inspector, Edison Electric Illuminating Co. of Brooklyn, 360 Pearl St.; residence, 265 Prospect Pl., B'klyn, N.Y.	W. S. Barstow. E. F. Peck. E. R. Knowles.

Total, 21.

Associates Transferred to Membership:

Approved by Board of Examiners, May 10th, 1901.

BARTON, PHILIP PRICE	Asst. Supt. Niagara Falls Pr. Co., Niagara Falls, N. Y.
CHILD, CHAS. T.	Technical Editor, Electrical Review, N. Y.
GARFIELD, ALEX. STANLEY	Engineer, Cie Thomson-Houston, 27 Rue de Londres, Paris, France.
HILL, GEORGE	Consulting Engineer, 150 Fifth Ave., N. Y.
PERRY, JOHN	Royal College of Science, London.
PINKERTON, ANDREW	Electrical Engineer, American Sheet Steel Co., Vandergrift, Pa.
SETHMAN, GEO. HENRY	Mechanical and Electrical Engineer, Skinner & Sethman, Denver, Col.
SPARKS, CHAS. PRATT	Chief Engineer County of London Electric Lighting Co., Surrey, Eng.
SWINTON, A. A. CAMPBELL	Consulting Electrical Engineer, 66 Victoria St., London, S. W., England.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, Sept. 27, 1901.

The 156th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by Prest. Steinmetz at 8.30 P. M.

THE SECRETARY :—At the meeting of the Board of Directors this afternoon the following associates were elected :

AROZARENA, RAFAEL MAXIMO DE	Consulting Engineer ; City of Mexico, Mexico.	C. T. Hutchinson. Louis Duncan. C. F. Beames.
AYLSWORTH, JONAS WALTON	Experimenter and Chemist, Edison Laboratory ; residence, 228 Midland Avenue, East Orange, N. J.	T. A. Edison. A. E. Kennelly. F. R. Upton.
BAILEY, LEON W.	Assistant Engineer, Eddy Electric Co., Windsor, Conn.	H. B. Coho. W. R. C. Corson. H. E. Heath.
BAKER, JOSEPH B.	Consulting Electrical Engineer, 40 Lincoln Street, Boston, Mass.	John Balch Blood. Chas. A. Stone. A. N. Mansfield.
BAYNE, HOWARD	Student Senior Class, Electrical Engineering, Columbia University; residence, Riverside Drive, cor. 108th St., N. Y. City.	M. I. Pupin, F. B. Crocker. J. J. Carty.
BELL, ALONZO C.	Owner and Manager, Bell Electric Motor Co., 197 Wooster St.; residence, 83 East 116th St., N. Y. City.	Chas. J. Bogue. Max Osterberg. Max Loewenthal.
BENNETT, EDWARD	Electrical Engineer, Westinghouse Electric and Mfg. Co.; residence, 530 Sheridan Ave., Pittsburg, Pa.	C. F. Scott. Murray C. Beebe. A. J. Wurts.
BOONE, WILLIAM KENNETH	Electrician, Jalapa R. R. & Power Co., Apartado 91, Jalapa, V. C. Mexico.	Geo. Greenwood. M. R. Gutieriez. Carlos Yslas.

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BRAUN, CHRISTIAN EDWARD	Draughtsman, Western Electric Co.; New York City; residence, 317 Nostrand Avenue, Brooklyn, N. Y.	G. A. Hamilton. O. A. Bell. J. D. Hathaway, Jr
CLIFT, ARTHUR S.	Mechanical Engineer, Crocker-Wheeler Co., Ampere, N. J.	S. S. Wheeler. Gano S. Dunn. F. V. Henshaw.
COGHLIN, JOHN P.	Electrical Engineer and Contractor, Page Electric Co., 24 Pearl St., Worcester, Mass.	Chas. F. Scott. Jno. S. Peck. A. J. Wurts.
DARLING, EDWARD ALBERT	Engineer, Edison Portland Cement Co., Stewartsville, N. J.	Thos. A. Edison. F. B. Crocker. M. I. Pupin.
DEAN, WALTER CLARK	Laboratorian, U. S. Government, (Navy), 197 Granby St., Norfolk, Va.	W. L. Puffer. W. L. Smith. T. P. Thompson.
DE CROW, CHARLES EDWARD	In charge of Power Apparatus, Output Dept., Western Electric Co., 242 S. Jefferson St.; residence, 996 Flournoy St., Chicago, Ill.	V. R. Lansingh. R. A. Widdicombe C. D. Crandall.
DODD, SAMUEL THOMSON	Engineer Railway Dept., Stanley Electric Mfg. Co., Pittsfield, Mass.	C. C. Chesney. John F Kelly. F. A. C. Perrine.
DOPP, WILLIAM HUGH	Drawing Room Foreman, Eddy Electric Mfg. Co., Windsor, Conn.	H. B. Coho. W. R. C. Corson. H. E. Heath.
DOUD, CHARLES HAMILTON	Student Columbia University, 30 W. 44th Street, New York City.	F. B. Crocker. G. F. Sever. L. B. Stillwell.
DRESSEL, JOHN HATHAWAY	Assistant Engineer on Switchboards, Wagner Electric Co.; residence, 3026 Locust St., St. Louis, Mo.	S. L. G. Knox. R. McClenathan. H. S. Carhart.
DYKE, OWEN ARTHUR WYNNE	Acting Electrical Manager, Lloyds & Co, Observatory Road, near Capetown, South Africa.	Jos. Wetzler. J. E. Lloyd. J. Denham.
GEORGE, JAMES ZACKARIAH	General Manager and Chief Engineer, Street Railway and Lighting Plant, Vicksburg, Miss.	Geo. W. Knox. C. G. Armstrong. James Lyman.
GIBBONEY, WILLIAM KENT	Chief Lineman, The Niagara Falls Power Co., 11 Sugar St., Echota, Niagara Falls, N. Y.	H. W. Buck. P. M. Lincoln. L. B. Stillwell.
HEMINGWAY, ALBERT FRANKLIN	Chief Draughtsman, The Western Electric Co.; residence, 143 W. 122d St., New York City.	O. A. Bell. H. F. Albright. G. F. Atwood.
HOLBROOK, FREDERICK MONTGOMERY	Chief Electrician, The Browning Mfg. Co., 489 Juneau Place, Milwaukee, Wis.	Gano S. Dunn. John J. Carty. M. I. Pupin.
JOHNSON, WARREN S.	Johnson Electric Service Co., 120 Sycamore St., Milwaukee, Wis.	D. C. Jackson. B. V. Swenson. B. Frankenfield.
KELLER, CARL A.	Assistant Engineer, J. G. White & Co., Monroe, Mich.	D. C. Jackson. S. W. Childs. H. A. Lardner.

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LYNDON, LAMAR	Consulting Engineer, Park Row Bldg.; residence, 102 W. 84th St., N. Y City.	H. W. Blake. T. C. Martin. W. D. Weaver.
MAGIE, LOUIS DEWITT	Works Engineer, Canadian General Electric Co., Peterborough, Ont.	F. A. C. Perrine. C. C. Chesney. D. B. Rushmore.
MARLAND, WILLIAM JOHN BAILEY	Electrical Engineer, 212 West 124th Street, New York City.	Geo. F. Sever. L. Stieringer. H. C. Cushing, Jr.
MCCONAHEY, WILLIAM M.	Electrical Engineer, Western Electric Co., 3600 Wabash Ave., Chicago, Ill.	V. R. Lansingh. H. H. Wait. E. P. Warner.
MCGRAW, JAMES H.	President, McGraw Publishing Co , 120 Liberty St., New York City; residence, Madison, N.J.	W. S. Barstow. Carl Hering. O. T. Crosby.
MILLER, WALTER H.	Manager of Record Dept., (Phonograph) with Thomas A. Edison; residence, 28 Mt. Vernon St., Orange, N. J.	L. Stieringer. A. E. Kennelly. Thos. A. Edison.
MORRISON, WILLIAM JAMES, JR.	Stock Broker, Consolidated Stock Exchange; also experimental electro-chemistry, Ridgefield Park, N. J.	Wm. Maver, Jr. H. F. Albright. G. A. Hamilton.
NEWMAN, FRED JACOB	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Chas. F. Scott. N. W. Storer. C. E. Skinner.
NORTHRUP, EDWIN FITCH	Chief Engineer (Electrical) Rowland Telegraph Co., Johns Hopkins Ave., Baltimore, Md.	B. B. Brackett. Carl Hering Irving B. Smith.
PARKER, LINDSAY R.	Student. Columbia University. 345 State Street, Brooklyn, N. Y.	M. I. Pupin. F. B. Crocker. F. Townsend.
PARKHURST, CHARLES WILLIAM	Supt. of Electrical Dept., Cambria Steel Co., Johnstown, Pa.	J. H. Granbery. Thos. Duncan. R. S. Masson.
PATTERSON, GEORGE WASHINGTON, JR.	Junior Professor of Physics, University of Michigan, 814 S. University Ave., Ann Arbor, Mich.	H. S. Carhart. Chas. R. Cross. Wm. L. Puffer.
PETICOLAS, SHERMAN GOODWIN	Sales Representative and Electrical Engineer, Bullock Electric Mfg. Co.; P. O. Box, 585, El Paso, Texas.	H. H. Humphrey. E. L. Nichols. Ralph W. Pope.
RICHTBERG, HERMANN ANDREAS	Electrical Engineer, Westinghouse Electric and Mfg. Co.; residence, 205 W. 41st St., New York City.	Henry Morton. Wm. E. Geyer. Albert F. Ganz.
RODGERS, ASHMEAD GRAY	Foreman of Winding Dept., Eddy Electric Mfg. Co., Windsor, Conn.	H. B. Coho Wm. R. C. Corson H. E. Heath.
SAGE, DARROW	In Testing Dept., General Electric Co., Schenectady, N. Y.; residence, 501 W. 113th St., New York City.	F. B. Crocker. G. F. Sever. C.S.Aylmer-Small
SIMPSON, ERNEST LEE	Electrical Engineer. The Mexican Gas and Electric Light Co., Santa Clara, No. 7, Mexico City, Mex.	S. Allen Dyer. L. W. Henry. C. F. Beames.

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SMITH, FRANK WARREN	Superintendent, The Cutler-Hammer Mfg. Co., 20 Charles St., Westfield, N. J.	C. M. Wilkes. Bion J. Arnold. R.H.Mansfield,Jr
SMITH, SAMUEL WILLIAM	General Storekeeper and Purchasing Agent, Lachine Rapids Hydraulic and Land Co., Ltd., 160 McCord St.; residence, 172 Versailles Street, Montreal, Can.	I. A. Taylor, L. A. Howland. Gustavo Lobo.
SPOEHRER, HERMANN	Laboratorian, in charge of Test Room, Equipment Dept., New York Navy Yard; residence, 472 2nd Ave., New York City.	T. Wolcott. J. Martin. W.V.N.Powelson.
SUDLOW, HARRY	City Engineer, City of Washington; box 26, Washington, Georgia.	A. M. Schoen, Jas. A. Wotton. Edw. J. Willis.
TERVET, ROBERT	Technical Engineer, Western Electric Co., North Woolwich, London; residence, 54 Penshurst Road, South Hackney, London, N. E., England.	H. F. Albright, G. A. Hamilton. Ralph W. Pope.
TOBEY, HARRY WILLARD	Member of the Engineering Dept, Stanley Electric Mfg. Co., 36 Oxford St., Pittsfield, Mass.	C. C. Chesney. John F. Kelly. F. V. T. Lee.
TYNDALL, CHARLES H.	Ph. D., Minister Reformed Church, 137 South Sixth Ave., Mt. Vernon, N. Y.	Ralph W. Pope. W. J. Hammer. F. E. Kinsman.
WALKER, MILES	Electrical Engineer, The British Westinghouse Electric and Mfg. Co., Ltd.; residence, 413 Pitt St., Pittsburg, Pa.	Chas. F. Scott. Percy K. Thomas. C. E. Skinner.
WELLS, GEORGE EUGENE	Consulting Electrical Engineer, Ruebel & Wells, 817 Clarendon Ave., St. Louis, Mo.	F. Schwedtmann. W. A. Layman. H. A. Wagner.
WILDER, HENRY WINDSOR	Electrical Engineer, Hudson River Telephone Co., Albany, N. Y.	O. A. Bell. Paul G. Burton. G. F. Atwood.
WILER, CARL	Electrical Engineer, Western Electric Co., Chicago, Ill.	Henry H. Wait. E. P. Warner. V. R. Lansingh.
WILSON, HENRY CLINTON	Chief Engineer, Chapman Double Ball Bearing Co., 49 Wall St., N. Y. City.	W. J. Hammer. F. E. Kinsman. Ralph W. Pope.

Total 54

Associates transferred to Membership:

Approved by Board of Examiners. July 19th, 1901.

F. A. MUSCHENHEIM	Electrical Engineer, Western Electric Co., New York City.
H. P. DAVIS	Engineer of Detail Department, Westinghouse E. & M. Co., Pittsburg, Pa.
H. E. MOLÉ	with J. G. White & Co., New York City.
FRANK W. ROLLER	Electrical Engineer, 203 Broadway, New York City.

Dr. Matthews then presented the following paper:

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A paper presented at the 156th Meeting of the American Institute of Electrical Engineers, New York, September 27th, 1901, President Steinmetz in the Chair.

AN IMPROVED APPARATUS FOR ARC-LIGHT PHOTOMETRY.

BY CHARLES P. MATTHEWS.

The usual process in arc-light photometry involves the determination of the distribution curve of luminous intensity in a vertical plane through the axis of the carbons, and the subsequent integration of a derived curve in rectangular co-ordinates (the Rousseau diagram).[1] The ordinate of this latter curve is the measured intensity, and the increment of the abscissa is proportional to the area of the elementary zone which such intensity illuminates of an imaginary sphere about the source. The mean ordinate of this derived curve is the value sought. Under the most favorable conditions this task is a tedious one, several hours being usually required for its completion.

Methods designed to shorten this process, through the production upon the photometer screen of an illumination proportional to either the mean spherical or mean hemispherical intensity of the source are not new. Of these integrating methods, the writer is aware of two due to Blondel,[2] and one due to Houston and Kennelly.[3]

Unfortunately, two of these methods are adapted only to the photometry of the open arc, while the third, although worked

1. See Appendix.

2. The Lumenmètre. *L'Éclairage Électrique*, March, April, May, 1895. The Photomesomètre. *L' Éclairage Électrique.*

3. *Electrical World*, xxvii: 509. 1896.

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out in a masterly manner by Blondel, requires a somewhat elaborate preliminary calibration. It is the writer's purpose to describe here an equipment which he has designed for the Photometric Laboratory of Purdue University, where it is now in satisfactory operation. This piece of apparatus, while embodying certain features of Blondel's apparatus, combines simplicity of operation with adaptability to either the open or enclosed arcs.

Theory of the Method.

The mean spherical intensity and the mean hemispherical intensity of a source whose photometric surface is one of a revolution are given by the expressions:

$$I_{ms} = \frac{1}{2}\int_0^{\pi} I_\theta \sin\theta \, d\theta^*$$

$$I_{mhs} = \int_0^{\pi/2} I_\theta \sin\theta \, d\theta.$$

Where I_θ is the intensity at an inclination of θ to the vertical. If the intensity I_θ be taken at n equal intervals through 180°, or n' equal intervals through 90° in a vertical plane, we may write

$$I_{ms} = \frac{\pi}{2n}\sum_0^{\pi} I_\theta \sin\theta$$

as the mean spherical intensity and

$$I_{mhs} = \frac{\pi}{2n'}\sum_0^{\pi/2} I_\theta \sin\theta$$

as the mean hemispherical intensity—expressions which are quite correct if n and n' be sufficiently large.

For example, let us consider the hypothetical distribution of intensity shown in Fig. 1, namely, a circle tangent to a vertical line. Here I is a known function of θ and we have

$$I_{ms} = \tfrac{1}{2}\int_0^{\pi} I_0 \sin^2\theta \, d\theta$$
$$= 78.5$$

if I_0 be taken as 100.

*See Appendix.

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Taking now $\Delta\,\theta = 15°$ or $n = 12$, we have

TABLE I.

θ	$100 \sin^3 \theta$
0	0.
15	6.7
30	25.
45	50.
60	75.
75	93.3
90	100.
105	93.3
120	75.
135	50.
160	25.
175	6.7
	600.

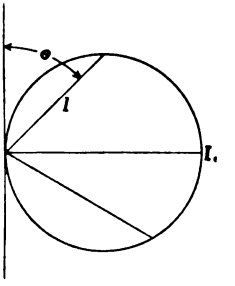

FIG. 1.

Whence

$$\sum_0^\pi 100 \sin^3 \theta = 600 \text{ and } I_{ms} = \frac{\pi}{2 \times 12} \times 600 = 78.5$$

It thus appears that with $n = 12$, the approximate formula yields a result amply correct.

To produce on the photometer screen an illumination proportional to the mean spherical intensity of the source, it is necessary, as the formula shows, (1) to direct towards the photometer the beams of light which the eye of an observer would receive if he were to view the source at angular intervals of 15 degrees in a vertical plane, and (2) to reduce the intensity of the light in these directions in the ratio of the sine of the angle between the direction of view and the vertical. The method of accomplishing this is described below.

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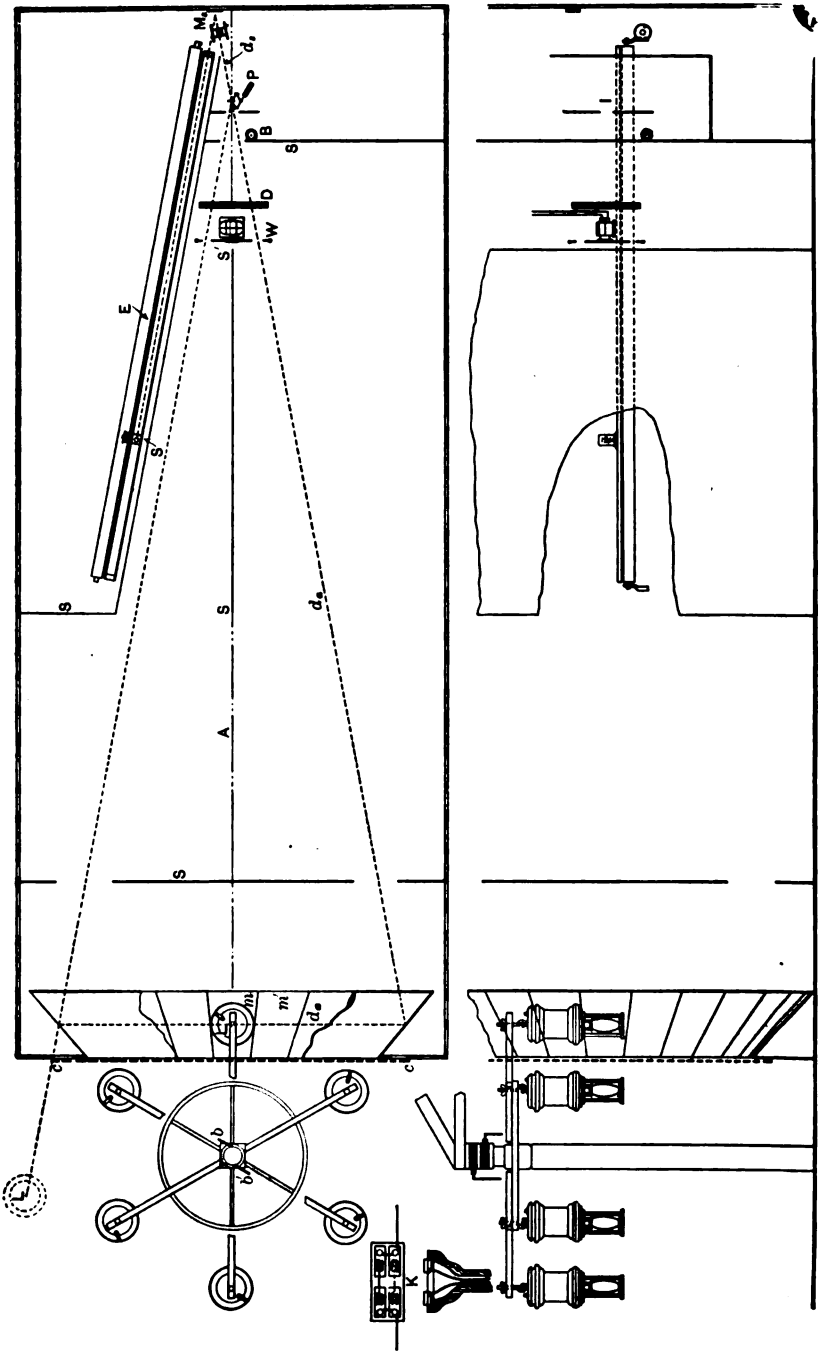

FIG. 2.—Plan and Elevation of Photometer Room.

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Description of Method.

A ring of 24 large trapezoidal mirrors, M, M, surrounds the arc. This system of mirrors constitutes a truncated, 24-sided pyramid. The inclination of the mirrors to the axis A of the system is such that the eye, placed at the photometer P, sees 24 images of the lamp L, of which L′ is the horizontal one, precisely as if the mirrors being absent, one were to travel in a circle about the arc in the plane 00′ stopping at 15° intervals. Figs. 3 and 4 show the aspect of this series of images from a point

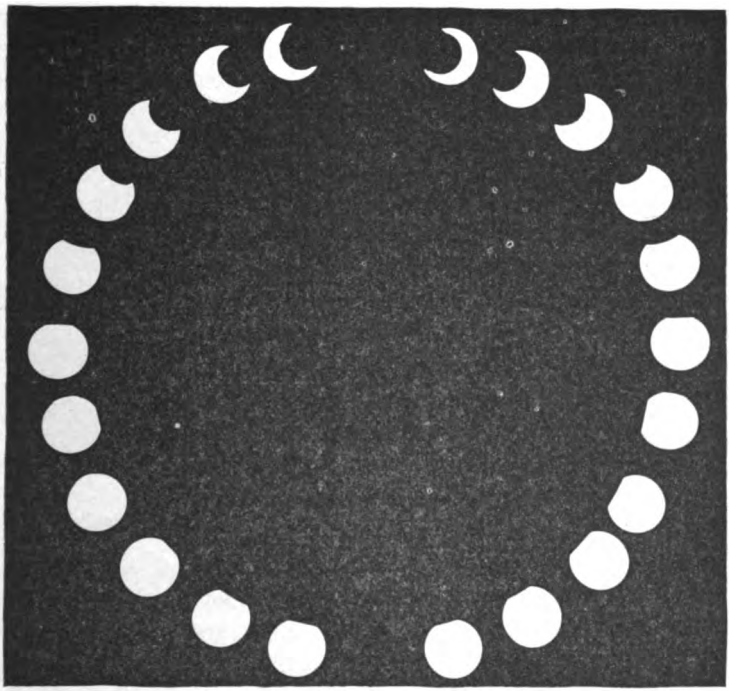

Fig. 5.—Arrangement for the Determination of the Mean Spherical Intensity. [The slight amount of displacement in Figs 3 and 4 is due to the fact that the camera could not be placed in the optical center of the system.]

near the photometer. The first figure shows the entire set of images as used in the determination of the mean spherical intensity, and the second figure the lower images only for the determination of the mean hemispherical intensity, as in the case of lamps with shades. As actually used, the top and bottom mirrors were left out, not because there may not be light in these

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directions, but because these intensities, when multiplied by sine 0°, do not contribute to the mean spherical intensity. Direct light from the arc is intercepted by a black screen s.

This system of mirrors serves then to direct the light to the photometer screen in the chosen directions. The second condition is that the intensity of each beam of light shall be reduced in the ratio of the sine of the vertical angle. I have done this by a polygonal glass disk D, composed of as many sectors as there are mirrors. These sectors are smoked until they give the desired absorption. In order that the film of smoke may be permanent, the ring of smoked sectors is covered by two plates

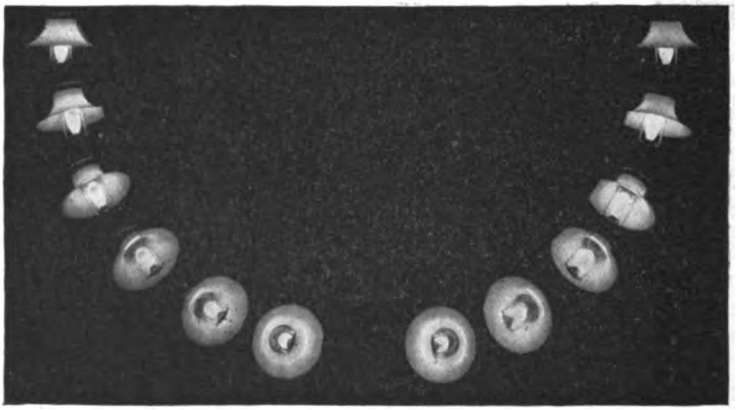

FIG. 4.—Arrangement for the Determination of the Mean Hemispherical Intensity.

of plane glass. These plates cover but do not touch the smoked surfaces. The three thicknesses of glass are firmly bound together, and the screen as a whole may be handled without fear of changing its absorption. The precaution must be taken to thoroughly clean its external surfaces before making measurements. An essential condition to the success of this method is that the photometer screen should receive light through any given sector from the image in the corresponding mirror and from no other. That this condition is fulfilled, can easily be determined. Thus, if all the mirrors be covered except the horizontal one, and all the sectors be covered except the sector just above the horizontal, that is, at 15° A, then if the patch of light produced by this arrangement of the apparatus falls not

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upon the photometer screen, but upon the black surface in the vicinity of the photometer, the required condition is met. The sectored disk is best put in place by replacing the photometer screen by a cardboard pierced by a small opening. The observer can then sight through this hole, and ascertain the adjustment of the disk with reference to the system of mirrors.

Constants of Mirrors and Glass.

The mirrors are of good quality, French plate glass. Their reflection coefficients were carefully determined for the incidence at which they are used. Some inequalities were found, as would be expected, although the maximum difference from the mean value of .815 is only $\pm$ 2.9 per cent. The following table gives the coefficients of the 24 mirrors.

TABLE II.

Value of Mirror Coefficients K_θ.

Mirror Number.	K_θ	Mirror Number.	K_θ
1	.796	13	.820
2	.830	14	.832
3	.803	15	.798
4	.814	16	.818
5	.791	17	.818
6	.812	18	.809
7	.812	19	.798
8	.803	20	.812
9	.832	21	.812
10	.809	22	.812
11	.839	23	.830
12	.834	24	.812

It will be seen that these coefficients occur in pairs. This would lead one to believe that two mirrors were cut from one piece of glass. An inspection of the edges of the mirrors showed that this was very probably the case. The values are so nearly equal that for purposes of arc-light photometry sufficient accuracy would be obtained by using the mean value of .815. However, in order that the apparatus might be used for the measurement of steady sources, I have made up for variations in K_θ in the smoking of the corresponding glass sectors. That is to say, if the coefficient of a particular mirror were high, the corresponding glass sector was smoked a little heavier than would otherwise be done. In all cases the formula

$$(K_g K_s) K_\theta = (K_0 K_g) \sin \theta$$ was satisfied.

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Where K_g = transmission coefficient of glass

K_s = transmission coefficient of layer of smoke corresponding to angle θ.

K_θ = reflection coefficient of mirror at angle θ

K_0 = reflection coefficient of horizontal mirror.

Since K_g and K_s must, of necessity, be obtained together, we have as the required transmission coefficient for the θ sector

$$K_g K_s = \frac{K_0 K_g \sin \theta}{K_e}$$

This value was computed for each sector and the glass smoked accordingly. It will be seen from this that the intensities are cut down as a whole in the ratio $K K_g : 1$, and furthermore, separately in the ratio $\sin \theta : 1$.

The mirrors were paired and put in position according to the following table:

TABLE III.

Position of Mirrors.

Position.	Mirrors.	Mean Constant at 40°
0	6 and 7	.812
15A	22 " 24	.812
30A	9 " 14	.832
45A	15 " 19	.798
60A	11 " 12	.837
75A	1 " 5	.793
15B	20 " 21	.818
30B	16 " 17	.818
45B	2 " 23	.830
60B	10 " 18	.809
75B	3 " 8	.803

Constant of Mirror behind Photometer at 12½° = .901.

Some care and skill are necessary to produce a uniform coating of smoke of just the required density. I have found it convenient to use a sheet iron chamber, fitted with a suitable flue, and pierced near the top with a small opening for the introduction of the glass. This chamber must be placed near one end of the photometer bar in order that the absorption of the glass may be tested as frequently as may be necessary. The setting of the photometer being predetermined, each sector is smoked until it shows the required absorption. There is a tendency for the coating to form most heavily near the edges of the glass. This may

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be overcome by providing a guard ring of glass of the same thickness as the piece to be smoked, the whole being mounted in a convenient holder. The best results will be obtained by holding the piece of glass vertically in the smoke chamber, occasionally reversing the piece. Turpentine is a good combustible, but it must be introduced into the receptacle at the base of the chamber in small quantities, otherwise the combustion will be so violent as to produce a flocculent deposit on the glass.

In testing the glasses it is best to use a small source of light, such as a narrow slit in front of a straight filament glow-lamp. Any inequalities in the coating of smoke can be detected by moving the glass about in front of this opening, care being taken that the same plane is maintained. It will be seen in Fig. 2 that the incidence of the light upon the glass is not quite normal. Care was taken to maintain this same incidence in the absorption tests.

At M_s is shown a mirror for directing the light from the temporary standard to the photometer. This mirror might have been omitted had not the limits of the photometer room already been taxed to the utmost. Still better, if the mirrors were from one large piece of glass, the direction of the photometer bar might be such that the same incidence would be had on M_s as upon the others. In this case, the correction for the mirror absorption would be eliminated.

The illumination upon the arc side of the photometer screen is, of course, very intense. It is necessary to reduce this illumination. For this purpose, I have used a rotating wheel w, provided with a large number of narrow radial slots. It is quite essential that the number of open slots should be large, as otherwise the illumination on the photometer screen will be seen to beat or pulsate when measurements are being made on the alternating arc. In order to avoid the error found by Ferry[1] I have determined the constant of this wheel by direct experiment on the arc itself, and not by calculation. The mean of several determinations gives

$$\text{Transmission constant sectored wheel} = K_w = .090$$

The number of slots in this wheel is 48, which gives a frequency amply great at the normal speed of the motor used for driving the wheel.

1. *Physical Review*, vol. i, p. 338.

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A possible source of error is the diffusion of the smoked glass disk. That is to say, since the disk receives a certain flux of light dependent upon the solid angle which it subtends from each image as a center and upon the intensity of such image, it becomes, to some extent, a secondary source. The direct measurement of this is a matter of some difficulty. To determine if the correction for this diffusion were of importance, I proceeded as follows: The longitudinal screen ss' was removed, the mirrors to the left of the vertical were covered, and likewise the right half of the sectored glass disk. With an arc of ordinary intensity in the center of the mirror system, it is evident that the left half of the sectored disk receives a flux of light about equal to that which it would normally receive with the longitudinal screen in position and the mirrors entirely uncovered. At the same time, no direct light from the images falls upon the photometer screen. Any illumination perceived under such circumstances would be due to the diffusive action of the glass. As a matter of fact, I found that with the temporary standard stopped down by a narrow slit, I could get a setting in this way when the sectored wheel was not in position, but when this wheel was running in its proper place the correction was entirely negligible. Hence no further attempt was made to take account of it.

The distance from source to photometer screen is large, being nearly nine metres. As the incidence of the light from the temporary standard is the same as that from the arc, no correction is here necessary.

A working equation may be developed as follows: Let

d_a = distance from arc to photometer screen.
d_s = distance from temporary standard to photometer screen.
K_0 = reflection constant of the horizontal mirror.
K_g = transmission constant of clean glasses.
K_s = reflection constant of mirror on glow lamp side.
K_w = transmission constant of wheel.
n, n' = number of mirrors.
f = factor due to the lack of normal incidence.

The illumination due to the arc is

$$i = \frac{2 K_0 K_g K_w f \sum_0^{\pi} I_\theta \sin \theta}{d_a^2}$$

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and that due to the standard of intensity I_s

$$i_s = \frac{f K_s I_s}{d_s^2}$$

Equating these two expressions, we have for the mean spherical intensity

$$I_{ms} = \frac{\pi}{2n} \sum_0^{\pi} I_\theta \sin \theta$$

$$= \frac{\pi K_s}{4 n K_0 K_g K_w} \left(\frac{d_a}{d_s}\right)^2 I_s$$

Similarly for the mean hemispherical

$$I_{mhs} = \frac{\pi}{2 n'} \sum_0^{\pi/2} I_\theta \sin \theta$$

$$= \frac{\pi K_s}{4 n' K_0 K_g K_w} \left(\frac{d_a}{d_s}\right)^2 I_s$$

With the following numerical values

$d_a = 865$ cm.	$n = 12$
	$n' = 7$
$K_0 = .812$	$K_s = .901$
$K_g = .690$	$K_w = .090$

These equations reduce to

$$I_{ms} = 1.17 \left(\frac{865}{d_s}\right)^2 I_s$$

$$I_{mhs} = 2.01 \left(\frac{865}{d_s}\right)^2 I_s$$

which are the working equations for the apparatus. Values of d_s are recorded on a drum in a manner already described by the writer.[1] (See Fig. 2.)

Values of $\left(\frac{d_s}{d_s}\right)^2$ are obtained by laying a graduated T-

1. *Physical Review*, vol. vii, p. 239, 1898.

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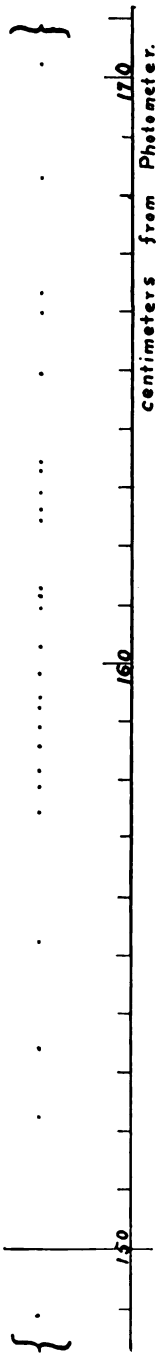

FIG. 5.—Specimen Record from Recording Drum.

square on the records obtained on the recording drum. A single covering on the drum suffices for the record of many tests. The records may then be worked out at the leisure of the operator. These records have always the same general characteristics, namely, many settings close together with scattered settings at each end. Figure 5 is a specimen record, and shows the usual range of fluctuation. The number of settings here is 30. This large number is necessary because of the fluctuations in the intensity of the arc, even with the steadying effect peculiar to the multiple mirror method. With hand fed arcs, a smaller number will suffice to give a value representative of the average performance of the arc. For the distribution curves, it suffices to uncover the mirrors in pairs and make settings in the usual way. The appropriate mirror constants must, of course, be used in working up the results.

As a check on the accuracy of the integrating method as compared with the usual method, I give the results of a test on an arc of the enclosed type. The value obtained from the Rousseau diagram is 308. That by the method described in this paper, 319. This agreement is within 3.4 per cent. When one considers the difficulty in maintaining an automatic feed arc under constant conditions during the time required to take the distribution curve, this must be considered as a very satisfactory agreement.

APPENDIX.

The product of the intensity I and the area of an elementary zone of radius r is

$$I_\theta \, d\,S = I_\theta \times 2\,\pi\,r\,R\,d\,\theta$$
$$= 2\,\pi\,R^2\,I_\theta \sin\theta\,d\,\theta.$$

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The mean spherical intensity is

$$I_{ms} = \frac{\int I_\theta \, d\, S}{4\,\pi\, R^2} = \tfrac{1}{2} \int_0^\pi I_\theta \sin\theta \, d\,\theta$$

The graphic method due to Rousseau is shown in Fig. 6, $\overline{O\ a\ b}$ is the given distribution. Draw a semi-circle of convenient radius. Project on the vertical $c\ d$ the points h, k. At f. g, lay off the corresponding intensities I_1, I_2. The area $\overline{c\ m\ n\ p\ d}$

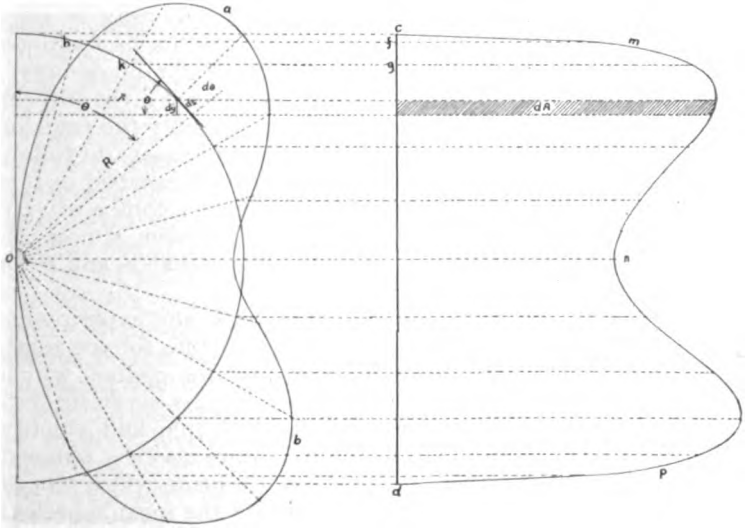

FIG. 6.

may be taken with a planimeter. This area divided by the base $\overline{c\ d}$ gives the mean spherical intensity, for

$$d\,\theta = \frac{d\,s}{R}$$

$$d\,s \sin\theta = d\,y$$

$$I_{ms} = \frac{1}{2\,R} \int_0^{2R} I_\theta \, d\,y = \frac{A}{2\,R}.$$

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Discussion.

The President:—Gentlemen, we have listened to a very interesting paper by Dr. Matthews describing a simplified method for photometrically determining arc lamps. I am quite sure there are many amongst you who are interested in the topic of photometry, especially of arc lamps, and who have given this matter a good deal of attention, so I hope that we shall have a very animated and interesting discussion.

I know that Dr. Sharp has given the matter of photometry a good deal of attention. We should be very glad to hear from him.

Discussion is now in order.

Dr. Clayton H. Sharp:—I think, Mr. President, that everybody engaged in the electric lighting business in any way is very greatly indebted to Dr. Matthews for the work that he has done in this extremely troublesome subject of arc light photometry. As Dr. Matthews said in the opening of his remarks, the subject has rather fallen into disrepute; but that is probably the fault of the very imperfect methods which it has been necessary to follow in the past. The improvement which has been described in this paper is an enormous one. The apparatus is of a comparatively simple nature and enables us to do what it has been almost impossible to do before; that is, to get truly reliable and close measurements on arc lamps.

I wish to ask Dr. Matthews if he has made any experiments which would indicate that it is possible to substitute for the rotating sectored disk a sheet of glass smoked after the method which he has described. Might not such a sheet of glass serve for cutting down the intensity of the light in a simple and equally effective method? And I should like to inquire also if a reduced copy of this same arrangement could not be made which would be equally applicable to the determination of the mean spherical candle power of the incandescent lamp by means of one measurement.

Dr. Matthews:—I can say, in reply to Dr. Sharp, that it is quite possible to cut down the light by means of the smoked glass and do away with the rotating sectored disk. There is nothing, of course, to prevent your smoking the horizontal sector quite heavily; then the others in a sine ratio. In that case you do away with the necessity of using the rotating disk. It is better, probably, to use the smoked glass, and I may say that I have done so with entire success. I have also in the laboratory just the device that Dr. Sharp speaks of, a miniature equipment like this for incandescent light photometry. Of course, when one comes to the photometry of incandescent lights, he no longer has to deal with a source whose photometric surface is one of revolution. By that I mean that the distribution of intensity through any given vertical plane is not the same as that through any

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other vertical plane. With the arc, the average distribution is constant in all vertical planes. Hence, with the incandescent lamp, one must spin the lamp to get the mean effect. The little instrument that I have operating in my laboratory for glow lamp work is provided with a rotator, and, except that I use smoked glass for cutting down light instead of the rotating sectored disk, is exactly like this apparatus described here. In the case of incandescent lights, there is not the necessity of cutting down the intensity that there would be in the case of the arc, so I presume that answers the question.

THE PRESIDENT:—Well, gentlemen, I am sure there is more to be said on this subject, and I should like to hear something further.

MR. C. J. SPENCER:—I would ask about the difference between the distribution of candle power in the alternating current and direct current lamps, I understand there is a difference.

DR. MATTHEWS:—Yes; there is a very marked difference, of course. Perhaps I can indicate it on the board. The upward lobe of light from the alternating arc is the same as the downward lobe, whereas from the direct current lamp the downward lobe is much greater than the upward, assuming the positive carbon to be above. However, with an enclosed arc you cannot predict what the distribution is going to look like. I think, perhaps, that the curves I published two years ago in the National Electric Light Association's report bring that point out. The contour and density of the opalescent globes, and the presence of reflecting surfaces in the lamp, modify the distribution. If you look at that report you will be struck by the fact that there seems to be no very uniform type of distribution. However, when we take the mean of all these curves from different lamps—twenty or twenty-five of them—we get a very smooth and regular curvature which may be taken as characteristic, I think, of the enclosed arc lamp.

MR. GEORGE T. HANCHETT:—Dr. Matthews has rescued arc light photometry from one of the worst starts any system of measurement ever had. I have no doubt that we all remember the day when they used to add north, south, east and west candle power together to make up 2,000, and this certainly is quantitative, to say the least. If I understand Dr. Matthews's apparatus correctly, it seems to me subject to a great deal of refinement when the necessary facilities are at hand for constructing something more elaborate. Dr. Matthews has had to experiment with flat pieces of glass because he could get them, and he chose a a large number of them to make the sigma equations as nearly as possible represent the integral sign. Now it seems to me that this method is of sufficient value to justify the attempt to make a mirror which shall be the frustum of a cone instead of the frustum of a pyramid. From Dr. Matthews's results as to the absorption of the different methods and from his statements it appears that

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the same piece of glass produces substantially the same absorption, and as the mirror was all of one piece, of course this error would be corrected and the necessity for the sectors of variable absorption in front of the screen would be done away with, and the continuous surface of the mirror would make the number of mirrors, as you might say, infinite, and the result correspondingly refined. We can twist glass into some very intricate shapes for cases where the demand is very small. In this case, it seems to me that the demand is such that we ought to get conical mirrors.

DR. MATTHEWS:—There is one serious objection, of course, to that. As soon as you depart from a plane mirror you get a focusing mirror. Now all these mirrors do is to give you the effect of 24 arc lights instead of one. If you used a curved mirror you would have a focusing effect, and what you would measure would be not intensity of light but flux of light. You would be collecting the flux of light and concentrating it. It is just like using a lens instead of a piece of plain glass.

MR. HANCHETT:—Do I understand that holds true of a ruled surface, one on which a straight line may be drawn? When a surface is curved and has curvature in three directions I can see where it might make some difference; but it seems to me it is simply a case of multiplying the number of mirrors. As long as you take the plane mirrors you can multiply them indefinitely according to the theory, if I understand it correctly. It is simply carrying it to the limit.

DR. MATTHEWS:—Not quite; you cannot go above a certain size, unless you increase the size of your diameter. You must see as you stand at the photometer, in each mirror, the image of the lamp in its entirety. Now if you multiply the number of mirrors and do not increase the diameter of your ring, then you will see only part of the lamp in each mirror. Of course that won't do. So really we do not need to think of the mirror at all. It is simply as if we had an arc lamp for each mirror, but set at different angles. Now as you increase the number of the mirrors, you would have to increase the diameter of the ring in order that you could still see in each mirror the complete lamp. I think I am right about that.

MR. HANCHETT:—The effect on the screen is the joint effect of all those reflections, and it seems to me the light from the conical mirror, even if it be a reflected image, ought to blend the results together in the same way.

DR. SHARP:—There is another difficulty connected with that proposition, and that is, it would be necessary for the smoking on the glass to be so graduated as to cut down the luminous intensity proportionately to the sine of the angle, continuously; a hard thing to get.

MR. HANCHETT:—That would be impossible, of course.

THE PRESIDENT:—Gentlemen, the arrangement devised by

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Dr. Matthews essentially consists in taking a simultaneous reading of the intensity of the arc lamp in the different directions and by the method described, by smoking the glass, integrating individual readings after multiplying by the sine. Here is one point that rather appears to me somewhat complicated; that is, the necessity of having the screen smoked exactly to a certain intensity of absorption. That can be done in the laboratory, but it is rather a delicate task. I believe it would be preferable if some method could be devised for doing this multiplication of the individual intensities before integration, mechanically, and not by absorption.

There is another question I would like to ask Dr. Matthews. How would it operate if the mirrors were replaced by white surfaces, to measure the illumination, as a secondary source of light; that is, instead of a circle of reflecting mirrors have a circle of white disks, and measure the total illumination coming from these disks?

Dr. Matthews:—I think we would then run into this very same difficulty I have spoken of, that we would be measuring this light flux, or what is sometimes called a quantity of light. In other words, it would be a question of how big these white surfaces were, since by making them smaller or larger we could get a different effect at the photometer. In other words, the white surface simply diffuses the light. The effect that you are going to get at the photometer would be dependent, I think, on the size of the diffusing surface.

The President:—But, again, shouldn't you expect if you have white surfaces at unit distance from the arc lamp and collect the total light flux issuing from those white surfaces, that you could from this reduce to the intensity of the source of light?

Dr. Matthews:—I think it would be possible. Only, then we would have to take into account the dimensions of the white surfaces. That is really the principle of Blondel's lumenmetre. It is based on the principle of collecting a certain portion of the flux of the light and concentrating it upon the photometer screen. But you have to know the relation between the diffusion of a definite surface and the quantity of light which that surface receives, and it is this fact which complicates Blondel's apparatus. That is the very effect that I attempted to avoid by using plane mirrors. We cannot, it seems to me, too clearly understand that the mirrors do not need to be thought of in the apparatus at all. It is just as if the mirrors were not there. You have simply 24 arc lamps turned at different angles. That is the aspect as you stand at the photometer and look towards the system. You do not really see any mirrors. You see 24 arc lamps. They are tipped up at various angles just as this picture shows, and especially Fig. 4, which, I think, shows it very well. They are arranged in a hemi-circle, in order that the photometric condition may be the same for all.

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THE PRESIDENT:—By using the same light-reflecting surfaces for the standard source of light also, would not that eliminate all the difficulties with the coefficient of diffusion of the white surfaces? Assuming that you do not compare directly the arc lamp with your standard incandescent lamp, or whatever it is, but compare the light diffused from a number of white surfaces at some distance from the arc in a circle around it, and the light issuing as diffused light from the white surfaces cut from the same material at a certain distance from the standard lamp, would not that eliminate the constants of diffusion, absorption, etc.? The reason I refer to that is this: It appears to me it would make it possible to eliminate the adjustment for the sine of the angle by having the area of these white diffusing surfaces proportional to the sine of the angle. While we then have to bring into the calculation the dimensions of the apparatus, it seems to me we could eliminate all coefficients of absorption, etc. I do not know whether that would be feasible, but I should like to hear.

DR. MATTHEWS:—I think it is feasible in part, but there is one serious objection. That is, that you have, in the usual photometric process to move either the photometer or the standard light. Now, as you move the photometer, you of course change the solid angles which each one of those surfaces subtends. It can easily be seen that that would complicate matters. In the use of a diffusing surface, the effect, of course, is dependent on the dimensions of the surface, since it is a question of how much flux that diffusing surface receives from the source, and an apparatus constructed on the plan that the President suggests would have to take account of these dimensions. Now, if we are to eliminate the size of this by having the same state of affairs around the standard lamp, it is difficult to see what we would do when we have to move the standard.

THE PRESIDENT:—Couldn't you get over this difficulty by not moving the standard lamp, but moving the point of observation between the two? Then both distances will change, but you can get over the whole range then.

DR. MATTHEWS:—I would not attempt to say that it is not possible, although I am afraid that the complications would be even worse than they are in the device that I have described.

DR. SHARP:—I would like to suggest, in regard to the President's proposition, that if we had a lot of diffusing surfaces receiving light, they would throw light one upon the other, and we would receive from each surface not only a certain definite fraction of the light which it receives from the source proper, but also a considerable luminous flux which is due to secondary reflections, reflections from the other diffusing screens. That is entirely done away with in the case of the plane mirrors properly constructed.

THE PRESIDENT:—I think you might get around that even by having one diffusing surface revolved around the light and giv-

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ing it such a motion that the angle of incidence will vary. The reason why I refer to this is that as a rule it is much easier outside of the laboratory to determine mechanical dimensions, distance and size than it is to measure coefficients of absorption. So that where you do not have the facilities of the laboratory at hand, any way of eliminating the necessity of determining coefficients of absorption and adjusting them is desirable.

MR. HANCHETT:—I should like to ask about the mean diameter of this frustum of a pyramid forming the mirror.

DR. MATTHEWS:—About six feet. I thought I could give you the exact measurement, but I am afraid I cannot. The total distance is 865 centimetres, and the diameter is not less than two metres.

MR. HANCHETT:—It is rather difficult to revolve a plane surface in such a circle as that, is it not?

DR. MATTHEWS:—Yes.

MR. WOODWARD:—I should like to ask in regard to that diagram. Those numbers are made up, as I understand it, from readings taken at stated intervals of time, are they not?

DR. MATTHEWS:—Yes.

MR. WOODWARD:—Has there ever been any attempt made to have a self-registering record?

DR. MATTHEWS:—I am afraid there never will be anything but the human eye to fix those values.

MR. WOODWARD:—Could not the selenium cell be used?

DR. MATTHEWS:—That has been attempted, but the question is, of course, with the selenium cell, what is its relation to the eye? The selenium cell and photographic effects and all other effects differ from the physiological effect.

MR. WOODWARD:—The thought in my mind was that there might be some fixed relation between the two, and by makin the comparison to start with, you then would have a record t look back to and save the time of the observer.

DR. MATTHEWS:—Yes, one would naturally think of that. Of course, though, such a calibration would have to be made for every different source that was used, for I think the quality of the radiation would affect it.

THE PRESIDENT:—Gentlemen, if there is no further discussion we are through with the topic of to-night's programme. The next meeting will be October 25th, and we expect then to introduce a modification of our present custom; that is, to have not one paper but several short papers dealing with the same topic and have these papers printed and distributed several days beforehand, so that the paper will not need to be read *in toto*, but only in abstract, thereby giving more time for discussion, and I expect that we shall have a very complete discussion then, since there will be several papers treating on the same matters. The subject will be announced in due time.

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[COMMUNICATED AFTER ADJOURNMENT BY A. E. KENNELLY.]

Professor Matthews's interesting paper illustrates the importance in practical photometry of employing an apparatus which at a single observation will supply the mean spherical candle power of a source of light. This is a somewhat difficult problem when the source of light, instead of being a small crater, as in the simple voltaic arc, or within a relatively small space, as in the incandescent lamp, occupies a large volume, as in a globe-covered arc lamp. Professor Matthews's solution of the problem in this case consists in mounting in a vertical circle containing the lamp a series of mirrors at 15° angular intervals, of such size to throw light upon the photometer screen from 24 parts of the lamp globe (or 22 parts in practice since the top and bottom mirrors can be omitted), and inserting an absorbent screen in the path of each mirror, in such a manner as to absorb the reflected light in proportion to the cosine of the altitude. As this gives rise to a 22-fold reflection, with a resultant total reflection of about 15-fold intensity on the photometer screen, a sectored revolving disk is used to subdue the measured illumination. Although the preparation and adjustment of such an apparatus must be somewhat laborious, there can be no doubt of the advantage which accrues from the use of the apparatus once in adjustment, since a single observation gives a close approximation to the mean spherical candle-power, and therefore to the total emission of light.

In the comparison of light sources the spherical candle-power is the only reliable basis. Just as mean horizontal candle-power is a fairer basis of comparison than horizontal candle-power in a single direction, so spherical candle-power, or total light emission is a fairer basis of comparison than mere mean horizontal candle-power, or light emission in a horizontal band. At the same time it seems doubtful whether it would be advisable to rate lamps commercially in terms of spherical candle-power. The mean spherical candle-power of an incandescent lamp is usually from 80 per cent. to 90 per cent. of its mean horizontal candle power, while in an arc lamp it is commonly from 0 per cent. to 100 per cent. in excess of the mean horizontal candle-power, but only 30 per cent. to 60 per cent. of the maximum candle-power, upon which the rating is ordinarily based. Consequently, to change the rating of lamps to the basis of mean spherical candle-power, although a gain in relative accuracy, would be commercially objectionable, because it would diminish incandescent lamp ratings about 15 per cent., and arc-lamp ratings about 50 per cent. The change, moreover, would be likely to bring about confusion between the two different ratings. It would seem preferable to refer spherical candle-power measurements to the amount of light emitted. Since a unit spherical candle-power represents 4π lumens of light emitted, a spherical Hefner means 12.566 Hefner

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lumens emitted, a spherical British candle-power 12,566 British lumens, and so on. Consequently, a 16-candle power incandescent lamp, instead of being reckoned as a lamp of, say 13.6 mean British spherical candle-power, would be a lamp of 170.9 British lumens, and if consuming 50 watts would have a light efficiency of 3.418 British lumens per watt. Similarly, an arc-lamp of 1,200 maximum British candle-power, instead of being rated as of, say 600 mean British spherical candle-power, would be a lamp of 7,540 British lumens, and if consuming 450 watts its light efficiency would be 16.75 British lumens per watt.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, Oct. 25, 1901.

The meeting of the INSTITUTE was held this date at 12 W. 31st street, and was called to order by President Steinmetz at 8:25 P. M.

THE PRESIDENT:—Gentlemen, will the meeting come to order. I give the floor to Mr. Pope, the Secretary, to make some announcements.

SECRETARY POPE:—Mr. President, at the meeting of the Executive Committee and the Board of Directors this afternoon, twenty-six associate members were elected. Their names are as follows:

Name	Address	Endorsed by
ABBOTT, WILLIAM L.	Chief Operating Engineer Chicago Edison Co., 139 Adams St.; residence, 3213 Beacon St., Chicago, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.
ALVERSON, HARRY BARTLETT	Superintendent, Cataract Power and Conduit Co.; residence, 40 Court St., Buffalo, N. Y.	D. C. Jackson. H. W. Buck. H. G. Stott.
ATKINS, CHARLES GILMAN	Engineer on Power Business, Chicago Edison Co., 139 Adams St., Chicago, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.
ATKINSON, WILLARD S.	Electrical Engineer and Faetory Manager, Zindars & Hunt; R. F. D. No. 5, New Brunswick, N. J.	W. C. Andrews. W. D. Weaver. T. C. Martin.
BAMBER, WILLIAM CHILDS	Electrical Engineer. Rapid Transit Subway Construction Co.; residence, 330 W. 57th St., New York City.	L. B. Stillwell. W. B. Potter. T. D. Boyles.
BENNETT, WILLARD S.	The S. S. White Dental Mfg. Co., New York City; residence, Charles Place, Elmhurst, N.Y.	H.V. A. Parsell, Jr. George H. Guy. T. J. Smith.
BROWN ROBERT G.	Electrician, 158 Montague St., Brooklyn, N. Y.	T. D. Lockwood. P. B. Delany. A. A. Knudson.

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Bunker, Arthur Clifford	Engineering Department, Stanley Electric Mfg. Co., 238 Crocker Building, San Francisco; residence, 1604 Central Ave., Alameda, Cal.	J. F. Kelly. C. C. Chesney. D. B. Rushmore.
Carlton, Willard Gilbert	Assistant to Chief Operating Engineer, Chicago Edison Co., 139 Adams St., Chicago, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.
Carpenter, Henry Cannon	Assistant in Engineering Department, New York Telephone Co.; residence, 113 East 69th St., New York City.	F. B. Crocker. G. F. Sever. R. W. Pope.
Conklin, Oliver Francis	Consulting Electrical Engineer, The Robbins & Myers Co., Springfield, Ohio.	G. F. Sever. H. H. Rustin. B. J. Arnold.
Cox, Frank Powell	Electrical Engineer, General Electric Co., Lynn, Mass.	Elihu Thomson. E. W. Rice. C. P. Steinmetz.
Ferguson, Louis Aloysius	General Superintendent, Chicago Edison Co., 139 Adams St., Chicago, Ill.; residence, 1401 Davis St., Evanston, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.
Gear, Harry Barnes	General Inspector, Chicago Edison Co., 139 Adams St., Chicago, Ill.	E. O. Schweitzer. James Lyman. Samuel Insull.
Harris, Grenville A.	Electrical and Mechanical Engineer, Takata & Co., 10 Wall St, New York City; residence, Elizabeth, N. J.	W. K. Dunlap. C. F. Scott. F. B. H. Paine.
Heany, John Allen	Expert, Peter Heany Development Co., 904 Quarry St., Philadelphia, Pa.	T. C. Martin. Max Osterberg. Max Loewenthal.
Janisch, Charles	Chief Engineer, The Siemens & Halske Co.; Siegmunds No. 12, Berlin, Germany.	A. H. Kruesi. C. P. Steinmetz. W. I. Slichter.
Junkersfeld, Peter	Assistant to Mechanical Engineer, Chicago Edison Co., 139 Adams St., Chicago, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.
Kruesi, Paul John	Assistant to Sales Manager, General Incandescent Arc Light Co., 572 First Ave.; residence, 330 West 57th St., New York City.	Samuel Insull. C. P. Steinmetz. Charles Batchelor.
Lukes, George Holt	Night Operating Superintendent, Chicago Edison Co., 139 Adams St., Chicago, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.
Morgan, Godfrey	General Manager, The Niagara Gorge R. R. Co.; residence, 815 Niagara Ave., Niagara Falls, N. Y.	F. A. Pattison. H. B. Coho. H. E. Heath.
Niesz, Homer Eldredge	Assistant to General Superintendent, Chicago Edison Co., 139 Adams St.; residence, 4211 Ellis Ave., Chicago, Ill.	James Lyman. Samuel Insull. C. M. Wilkes.

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PALMER, D. ALONSO	Superintendent, Campania Anonima de Redes Telefonicas de Ponce; Box 185, Ponce, Porto Rico.	C. C. Haskins. C. H. Wilson. R. W. Pope.
PALMER, GRANVILLE ERNST	Salesman, H. C. Roberts Electrical Supply Co., 802 Equitable Building, Baltimore, Md.	G. A. Thomson. J. J. Bellman. Horace Dowie.
SMITH, SAMUEL NEWTON	Manager of Sales, Submerged Electric Motor Co., 725 Temple Court, Minneapolis, Minn.	G. F. Sever. Luther Stieringer. P. B. Woodworth.
SWEETLAND, RALPH	Electrical Inspector, New England Insurance Exchange, 55 Kilby St., Boston; residence, Natick, Mass.	H. G. Reist. C. M. Goddard. F. E. Cabot.

Total 26.

Transferred from Associate to full Membership:

CARL L. DE MURALT, Baden, Switzerland.

THE PRESIDENT:—Gentlemen, members of the INSTITUTE and guests, the topic of to-night's discussion is the speed regulation of alternators, or rather the speed regulation of prime movers, in its relation to the parallel operation of alternators. We have a number of papers, the principal one by Mr. Keilholtz, on Angular Variation in Steam Engines, and several shorter papers from a number of gentlemen familiar with this subject, who will give us their experience. Consequently we have strictly to limit the time, and it has been decided to permit fifteen minutes for the abstracting of the main paper, ten minutes for each successive paper and five minutes for discussion. The various papers will now be presented.

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A paper presented at the 157th Meeting of the American Institute of Electrical Engineers, New York, October 25th, 1901, President Steinmetz in the Chair.

ANGULAR VARIATION IN STEAM ENGINES.

BY P. O. KEILHOLTZ.

INTRODUCTION.

The following investigation was undertaken with the view of determining the angular variation of a 29 x 60 x 56 cross compound vertical engine built by McIntosh, Seymour & Co., Auburn, N. Y., and direct connected to a M. P. 22–2000–100, 500-volt railway generator built by the General Electric Co. It is understood of course that the variation of angular velocity does not interfere with the successful parallel operation of direct current generators, but as the variation is caused by the engine, it is immaterial to this investigation as to the type of apparatus driven.

The paper is divided into two parts, theoretical and experimental. In the former part I have consulted and appropriated from papers written by the late Prof. Fleeming Jenkin, *Transactions of the Royal Society of Edinburgh*, vol. xxviii., 1879; and J. H. Macalpine, Esq., *Journal of the American Society of Naval Engineers*, vol. ix., No. 3. There is, however, sufficient originality to warrant giving the theoretical part in full.

I have been informed that the angular variation of an engine has been measured by driving a small direct current generator from the rim of the fly-wheel of the engine and balancing the E. M. F. of the generator by a storage battery. A voltmeter with a minimum amount of damping was then connected across the terminals of the generator and the deflection read. This would show the total velocity variation of the fly-wheel from which the

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space variation with a wheel revolving at constant speed could be calculated.

As before stated, it was intended to measure the angular variation of the 29x60x56 vertical cross-compound engine, but owing to the fact that the engine cannot be spared at the present time, the measurement was made upon a 24 x 45 x 42 horizontal tandem compound engine built by McIntosh, Seymour & Co., and direct connected to a M. P. 10–800–100 500-volt railway generator built by the General Electric Company. The peripheral speed of the fly-wheel rim of the vertical is 90 feet per second, and the tandem 83¾ feet per second. The difficulties of measurement would be practically the same, although the space variation of the vertical would be less than the tandem. The curves of turning moments of both engines are given, together with curves of velocity and space variation, and it is my intention to measure the space variation of the vertical engine when the engine can be spared for the purpose.

The data for the curves of steam and inertia turning moments for the vertical engine are given in Tables X and XI. Table X is formed from equations 4 and 25, the substituted values giving

$$\frac{M}{g}\,\omega^2\,r^2\,[+\,.05\sin\theta - .5\sin 2\theta - .15\sin 3\theta - .01\sin 4\theta]$$

and

$$\frac{R}{g}\,\omega^2\,r\,[-.0025\sin\theta - .296\sin 2\theta - .0975\sin 3\theta - .0047\sin 4\theta]$$

The running parts were carefully weighed, and are as follows:

Low pressure piston, rod and nut weighed.....	3320	lbs.
High " " " " " "	1988.5	"
Connecting rod complete, high and low, each.....	2944	"
Crosshead " " " " "	1203.5	"

High pressure crank leads 90°

The moment of inertia of the connecting rod about its center of gravity was obtained experimentally. The rod was swung about an axis which passed through the center of the wrist pin. A semi-circular wooden block to which was fastened a metal plate was inserted in place of the wrist pin, the whole resting

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upon the edge of a 4 x 4 angle. The moment of friction could be neglected as the amplitude of the vibration was less than one inch. In this way its length as an equivalent simple pendulum was obtained. The distance of the center of gravity from the axis of suspension was found by balancing the rod upon the edge of a 4x4 angle. With these measured quantities the moment of inertia of the rod about its center of gravity was found, and reduced to the terms of the equation,

$$I_c = 3.4\, R\, r^2$$

where $K = 0.53$; and $a = 0.2$. (The vertical is 5 cranks and the tandem 6 cranks).

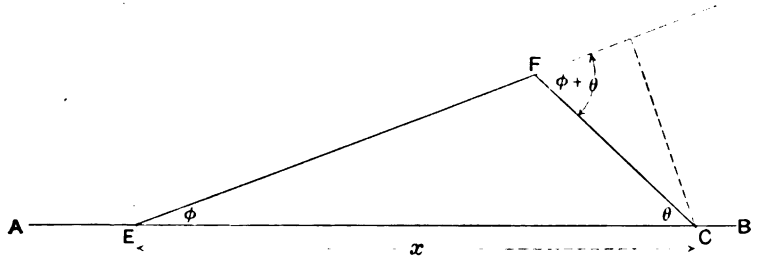

FIG. 1.

Length of connecting rod $E\,F$, l.
Length of crank radius $C\,F$, r.

$$\text{Call } \frac{r}{l} = a$$

Let a force P act at E in the direction $A\ B$ to find its turning moment about C.

Take origin of co-ordinates at C and call the distance $E\ C$, x, then the geometry of Figure 1 gives:

$$x = l \cos \varphi + r \cos \theta, \text{ and } \sin \varphi = a \sin \theta.$$

Substituting

$$x = \frac{r}{a}\,(1 - a^2 \sin^2 \theta)^{\frac{1}{2}} + r \cos \theta$$

Expanding the radical and substituting the values of the powers of sin θ in terms of cos 2 θ, cos 4 θ and cos 6 θ, we have:

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$$x = \frac{r}{a}\left|\begin{array}{l} 1 - \frac{a^2}{4} - \frac{3\,a^4}{64} - \frac{10\,a^6}{256} - \ldots. \\ + \cos 2\theta\left(\frac{a^2}{4} + \frac{a^4}{16} + \frac{15\,a^6}{256} + \ldots\right) \\ - \cos 4\theta\left(\frac{a^4}{64} + \frac{6\,a^6}{256} + \ldots.\right) \\ + \cos 6\theta\left(\frac{a^6}{256} + \ldots.\right) \end{array}\right| + r\cos\theta \qquad (1)$$

Differentiating with respect to time and considering the angular velocity of the crank constant, and equal to

$$\frac{d\theta}{dt} = \omega$$

we have:

$$\frac{d^2x}{dt^2} = \omega^2 r\left|\begin{array}{l} -\cos\theta \\ -\cos 2\theta\,(a + \frac{a^3}{4} + \frac{15}{64}\,a^5 + \ldots.) \\ +\cos 4\theta\left(\frac{a^3}{4} + \frac{3}{8}\,a^5 + \ldots.\right) \end{array}\right| \qquad (2)$$

The resolved part of the force P along the connecting rod is

$$\frac{P}{\cos\varphi}$$

and its turning moment about the crank shaft is

$$-\frac{P}{\cos\varphi}\,r\sin(\theta+\varphi)$$

The development of

$$\frac{\sin(\theta+\varphi)}{\cos\varphi}$$

in terms of $\sin\theta$ and multiples of that angle is as follows:

$$\frac{\sin(\theta+\varphi)}{\cos\varphi} = \frac{\sin\theta\cos\varphi + \cos\theta\sin\varphi}{\cos\varphi}$$

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$$= \sin\theta + \frac{a\cos\theta\sin\theta}{\sqrt{(1 - a^2\sin^2\theta)}}$$

$$= \sin\theta + \frac{a}{2}\sin 2\theta\,(1 - a\sin^2\theta)^{-\frac{1}{2}}$$

Expanding the quantity in parenthesis we have

$$\frac{\sin(\theta+\varphi)}{\cos\varphi} = \sin\theta + \frac{a}{2}\sin 2\theta\,(1 + \frac{a^2}{2}\sin^2\theta + \frac{3}{8}a^4\sin^4\theta + \frac{15}{24}a^6\sin^6\theta +)$$

Substituting for the powers of sin θ in the parenthesis their values in multiples of the angle, we have

$$\frac{\sin(\theta+\varphi)}{\cos\varphi} = \sin\theta + \frac{a}{2}\sin 2\theta \left|\begin{array}{l} 1 + \frac{a^2}{4} + \frac{9}{16}\frac{a^4}{16} + \frac{150}{768}a^6 + \ldots. \\ -\cos 2\theta\left(\frac{a^2}{4} + \frac{12\,a^4}{16} + \frac{225\,a^6}{768} + ..\right) \\ +\cos 4\theta\left(\frac{3\,a^4}{16} + \frac{90\,a^6}{768} + \ldots\ldots\right) \\ -\cos 6\theta\left(\frac{15\,a^6}{768} + \ldots\ldots\ldots\ldots\right) \end{array}\right|$$

Performing the multiplication indicated and collecting the terms we have

$$\frac{\sin(\theta+\varphi)}{\cos\varphi} = \sin\theta + \left|\begin{array}{l} +\sin 2\theta\left(\frac{a}{2} + \frac{a^3}{8} + \frac{15}{64}a^5 + \ldots..\right) \\ -\sin 4\theta\left(\frac{a^3}{16} + \frac{12\,a^5}{64} + \frac{285}{3072}a^7 +\right) \\ +\sin 6\theta\left(\frac{3\,a^5}{64} + \frac{90\,a^7}{3072} + \ldots\ldots\right) \\ -\sin 8\theta\left(\frac{15\,a^7}{3072} + \ldots\ldots\ldots\ldots\right) \end{array}\right|$$

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Therefore the turning moment due to a force P is

$$Pr \left| \begin{array}{l} +\sin\theta \\ +\sin 2\theta \left(\frac{a}{2}+\frac{a^3}{8}+\frac{15\,a}{64}+\ldots\ldots\right) \\ -\sin 4\theta \left(\frac{a^3}{16}+\frac{12\,a^5}{64}+\frac{285}{3072}a^7+\right) \\ +\sin 6\theta \left(\frac{3\,a^5}{64}+\frac{90\,a^7}{3072}+\ldots\ldots\right) \\ -\sin 8\theta \left(\frac{15\,a^7}{3072}+\ldots\ldots\ldots\ldots\right) \end{array} \right| \qquad (3)$$

To obtain the turning moment due to the steam forces substitute for P the pressures on the piston at the different crank angles.

To obtain the turning moment due to the inertia of the reciprocating parts other than the connecting rod, substitute for P the mass of the reciprocating parts multiplied by the acceleration obtained from equation (2) as follows:

$$\frac{M}{g}\omega^2 r^2 \left| \begin{array}{l} +\sin\theta \left(\frac{a}{4}+\frac{a^3}{16}+\frac{15\,a^5}{128}+\ldots.\right) \\ -\sin 2\theta \left(\frac{1}{2}+\frac{a^4}{16}+\frac{7\,a^6}{64}+\frac{6\,a^8}{256}+\right) \\ -\sin 3\theta \left(\frac{3\,a}{4}+\frac{5\,a^3}{16}+\frac{39\,a^5}{128}+\ldots\right) \\ -\sin 4\theta \left(\frac{a^2}{4}+\frac{3\,a^4}{16}+\frac{23\,a^5}{256}+\ldots.\right) \\ +\sin 5\theta \left(\frac{a^3}{8}+\frac{3\,a^5}{16}+\ldots\ldots\ldots\right) \\ +\sin 6\theta \left(\frac{a^4}{16}+\frac{a^6}{8}+\frac{6\,a^8}{128}+\ldots\ldots\right) \end{array} \right| \qquad (4)$$

To obtain the inertia forces of the connecting rod we proceed as follows:

The rod is acted upon by three forces designated by F_1, F_2, F_3.

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F_1 acts at the center of gravity of the rod in a direction parallel to the piston; F_2 acts along the rod towards the wrist pin, and F_3 acts at the center of percussion of the rod and at right angles to it as indicated in Fig. 2.

E, G and H, representing the wrist pin, center of gravity and center of percussion, respectively. G and H are distant d and λ from E.

The kinematical equations determining the motion of the rod are

$$F_1 = \frac{d^2 z}{dt^2}$$

$$F_2 = d\left(\frac{d\varphi}{dt}\right)^2$$

$$F_3 = d\frac{d^2\varphi}{dt^2}$$

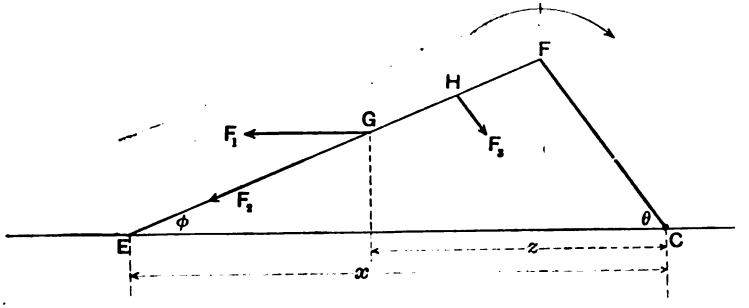

FIG. 2.

in which z, d and φ are respectively the abcissa of the center of gravity measured from the crank shaft, the distance of the center of gravity from the point E, and the angle the connecting rod makes with the center line of the engine.

The dynamical equations of the above forces where R is the mass of the rod are

$$\frac{R}{g} \cdot \frac{d^2 z}{dt^2}$$

$$\frac{R}{g} \cdot d \cdot \left(\frac{d\varphi}{dt}\right)^2$$

$$\frac{R}{g} \cdot d \cdot \frac{d^2\varphi}{dt^2}$$

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The turning moment about the crank shaft of the dynamical force F_1 is

$$-\frac{R}{g}\cdot\frac{d^2z}{dt^2}\cdot r\sin\theta$$

This force causes reactions at the guide and crank pin which are normal to the direction, and as the wrist pin is free to move in the direction of the force while the stub end of the rod is constrained by the crank pin, moments can be taken about the crank pin, and as the force passes through the center of gravity they are equal. The reaction on the crank pin is, therefore,

$$\frac{R}{g}\cdot\frac{(l-d)\sin\varphi}{l\cos\varphi}\cdot\frac{d^2z}{dt^2}$$

The turning moment due to this reaction is

$$-\frac{R}{g}\cdot\frac{(l-d)\sin\varphi}{l\cos\varphi}\cdot\frac{d^2z}{dt^2}\cdot r\cos\theta$$

The turning moment due to F_2 is

$$-\frac{R}{g}\cdot d\cdot\left(\frac{d\varphi}{dt}\right)^2 r\sin(\theta+\varphi)$$

The turning moment due to F_3 is

$$\frac{R}{g}\cdot d\cdot\frac{d^2\varphi}{dt^2}\cdot\frac{\lambda}{l}\cdot r\cos(\theta+\varphi)$$

The turning moment due to the connecting rod is the sum of

$$-\frac{R}{g}\cdot\frac{d^2z}{dt^2}\,r\sin\theta \tag{5}$$

$$-\frac{R}{g}\cdot\frac{(l-d)\sin\varphi}{l\cos\varphi}\cdot\frac{d^2z}{dt^2}\cdot r\cos\theta \tag{6}$$

$$-\frac{R}{g}\cdot d\cdot\left(\frac{d\varphi}{dt}\right)^2 r\sin(\theta+\varphi) \tag{7}$$

$$\frac{R}{g}\cdot d\cdot\frac{d^2\varphi}{dt^2}\cdot\frac{\lambda}{l}\cdot r\cos(\theta+\varphi) \tag{8}$$

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The geometry of the figure gives

$$z = x - d\cos\varphi\,;\ \text{and calling}\ \frac{d}{l} = K,$$

we have

$$z = x - \frac{K r}{a}(1 - a^2\sin^2\theta)^{\frac{1}{2}}$$

$$z = x - \frac{K r}{a}\left|\begin{array}{l} 1 - \frac{a^2}{4} - \frac{3\,a^4}{64} - \frac{10\,a^6}{256} - \ldots\ldots\ldots \\ +\cos 2\theta\left(\frac{a^2}{4} + \frac{a^4}{16} + \frac{15\,a^6}{256} + \ldots\right) \\ -\cos 4\theta\left(\frac{a^4}{64} + \frac{6\,a^6}{256} + \ldots\ldots\ldots\right) \end{array}\right| \qquad (9)$$

Differentiating with respect to time

$$\frac{d\,z}{dt} = \frac{d\,x}{dt} - \frac{K r\,\omega}{a}\left|\begin{array}{l} -\sin 2\theta\left(\frac{a^2}{2} + \frac{a^4}{8} + \frac{15\,a^6}{128} + \ldots\right) \\ +\sin 4\theta\left(\frac{a^4}{16} + \frac{3}{32}\,a^6 + \ldots\ldots\ldots\right) \end{array}\right| \qquad (10)$$

Again,

$$\frac{d^2 z}{dt^2} = \frac{d^2 x}{dt^2} - \frac{K r\,\omega^2}{a}\left|\begin{array}{l} -\cos 2\theta\left(a^2 + \frac{a^4}{4} + \frac{15\,a^6}{64} + \ldots\ldots\right) \\ +\cos 4\theta\left(\frac{a^4}{4} + \frac{3}{8}\,a^6 + \ldots\ldots\ldots\right) \end{array}\right| \qquad (11)$$

Substituting for

$$\frac{d^2 x}{dt^2}$$

its value from equation (2)

$$\frac{d^2 z}{dt^2} = \omega^2 r\left|\begin{array}{l} -\cos\theta \\ (K-1)\left\{\begin{array}{l} \cos 2\theta\,(a + \frac{a^3}{4} + \frac{15a^5}{64} + .) \\ -\cos 4\theta\left(\frac{a^3}{4} + \frac{3\,a^5}{8} + ..\right) \end{array}\right\} \end{array}\right| \qquad (12)$$

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Multiplying the above by $r \sin \theta$, we have

$$\frac{d^2 z}{dt^2} \cdot r \sin \theta = \omega^2 r^2 \begin{vmatrix} \sin\theta\,(1-K)\left(\frac{a}{2}+\frac{a}{8}+\frac{15}{128}a^5+\ldots.\right) \\ -\sin 2\theta\,(\tfrac{1}{2}) \\ -\sin 3\theta\,(1-K)\left(\frac{a}{2}+\frac{5a^3}{32}+\frac{39}{128}a^5+\right) \\ +\sin 5\theta\,(1-K)\left(\frac{a^3}{8}+\frac{3a^5}{16}+\ldots.\right) \end{vmatrix} \quad (13)$$

Equation (6) may be written

$$-\frac{R}{g} \cdot \frac{d^2 z}{dt^2} r \sin\theta\,(1-K)\frac{a\cos\theta}{\cos\varphi}$$

which we see is equation (13) multiplied by

$$(1-K)\frac{a\cos\theta}{\cos\varphi}, \text{ omitting } \frac{R}{g}.$$

The geometry of the figure gives $\sin\varphi = a \sin\theta$

Differentiating we get $\cos\varphi\, d\varphi = a\cos\theta\, d\theta$, or

$$\frac{d\varphi}{d\theta} = \frac{a\cos\theta}{\cos\varphi} = a\cos\theta\,(1-a^2\sin^2\theta)^{-\frac{1}{2}}$$

Expanding the quantity in parenthesis we have

$$\frac{d\varphi}{d\theta} = a\cos\theta\,(1+\tfrac{1}{2}a^2\sin^2\theta+\tfrac{3}{8}a^4\sin^4\theta+\ldots.)$$

Integrating

$$\varphi = a\sin\theta+\frac{1}{6}a^3\sin^3\theta+\frac{3}{40}a^5\sin^5\theta+\ldots. \quad (14)$$

Transforming

$$\varphi = \sin\theta\left(a+\frac{a^3}{8}+\frac{3}{64}a^5+\ldots.\right)$$

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$$- \sin 3\theta \left(+ \frac{a^3}{24} + \frac{3}{128} a^5 + \ldots.\right) \qquad (15)$$

$$+ \sin 5\theta \left(+ \frac{3}{640} a^5 + \ldots.\right)$$

Differentiating and calling the coefficients of sin θ, sin 3θ, sin 5θ, A_1, B_1 and C_1, respectively, we have

$$\frac{d\varphi}{d\theta} = \cos\theta\, A_1 - \cos 3\theta\, 3\, B_1 + \cos 5\theta\, 5\, C_1$$

Multiplying equation (13) by the above and again by $(1 - K)$ we have

$$\omega^2 r^2 \Big| \begin{aligned}
&- \sin\theta (1 - K) \left(\frac{A_1 + 3 B_1}{4}\right) \\
&+ \sin 2\theta (1-K)^2 \left(\frac{K_1 A_1}{2} - \frac{K_2 A_1}{2} + \frac{3 K_1 B_1}{2} - \frac{3 K_3 B_1}{2} + \frac{5 K_2 C_1}{2}\right) \\
&- \sin 3\theta (1 - K) \left(\frac{A_1}{4} + \frac{5 C_1}{4}\right) \\
&- \sin 4\theta (1-K)^2 \left(\frac{A_1 K_2}{2} - \frac{A_1 K_3}{2} + \frac{3 B_1 K_1}{2} + \frac{5 C_1 K_1}{2}\right) \\
&+ \sin 5\theta (1 - K) \frac{3 B_1}{4} \\
&+ \sin 6\theta (1 - K)^2 \left(\frac{A_1 K_3}{2} + \frac{3 B_1 K_2}{2} + \frac{5 C_1 K_1}{2}\right) \\
&- \sin 7\theta (1 - K) \frac{5 C_1}{2} \\
&- \sin 8\theta (1-K)^2 \left(\frac{3 B_1 K_3}{2} + \frac{5 C_1 K_2}{2}\right)
\end{aligned} \Big|$$

in which K_1, K_2 and K_3 are respectively the coefficients of sin θ sin 3θ, sin 5θ in equation (13).

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Performing the operations indicated we have

$$\omega^2 r^2 (1-K) \left| \begin{array}{l} -\sin\theta \left(\frac{a}{4} + \frac{a^3}{16} + \frac{15}{492} a^5 + \ldots\right) \\ -\sin 2\theta (1-K) \left(-\frac{a^4}{64} + \frac{510}{7680} a^6\right) \\ -\sin 3\theta \left(\frac{a}{4} + \frac{a^3}{32} + \frac{9}{512} a^5 \ldots\right) \\ -\sin 4\theta (1-K) \left(\frac{a^2}{4} + \frac{5a^4}{64} + \frac{448}{3072} a^6\right) \\ +\sin 5\theta \left(\frac{a^3}{32} + \frac{9}{512} a^5 \ldots\right) \end{array} \right| \qquad (16)$$

Adding equations (13) and (16) we have

$$\frac{R}{g}\omega^2 r^2 (1-K) \left| \begin{array}{l} +\sin\theta \left(\frac{a}{4} + \frac{a^3}{16} + \frac{45}{492} a^5 \ldots\right) \\ -\sin 2\theta (1-K) \left(-\frac{a^4}{64} + \frac{510}{7680} a^6\right) \\ -\sin 3\theta \left(\frac{3a}{4} + \frac{3a^3}{16} + \frac{165}{512} a^5 \ldots\right) \\ -\sin 4\theta (1-K) \left(\frac{a^2}{4} + \frac{5a^4}{64} + \frac{448}{3072} a^6\right) \\ +\sin 5\theta \left(\frac{5a^3}{32} + \frac{105}{512} a^5 \ldots\right) \end{array} \right| - \frac{R}{g}\omega^2 r^2 \sin 2\theta \tfrac{1}{2} \qquad (17)$$

which is the solution for the force F_1.

The development of the expression for the turning moment of the force F_2 is as follows:

From equation (15)

$$\frac{d\varphi}{dt} = \left[\cos\theta \left(a + \frac{a^3}{8}\right) - \cos 3\theta \frac{a^3}{8}\right] \omega$$

omitting the higher powers of a.

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Squaring and omitting powers of a greater than 2 we have

$$\left(\frac{d\varphi}{dt}\right)^2 = a^2 \cos^2\theta\,\omega^2 \qquad (16)$$

and

$$\begin{aligned}\sin(\theta+\varphi) &= \sin\theta\cos\varphi + \cos\theta\sin\varphi \\ &= \sin\theta\,(1 - a^2\sin^2\theta)^{\frac{1}{2}} + a\cos\theta\sin\theta \\ &= \sin\theta\,(1 - \tfrac{1}{2}a^2\sin^2\theta - \tfrac{1}{8}a^4\sin^4\theta - \tfrac{1}{16}a^6\sin^6\theta - \&c.) \\ &\qquad + a\cos\theta\sin\theta\end{aligned}$$

therefore

$$\begin{aligned}\sin(\theta+\varphi) = \sin\theta &\left(1 - \frac{3a^2}{8} - \frac{5a^4}{64} - \frac{55}{1024}a^6\right) \\ &+ \sin 2\theta\left(\frac{a}{2}\right) \\ &+ \sin 3\theta\left(\frac{a^2}{8} + \frac{5}{128}a^4 + \frac{21}{1024}a^6\right) \\ &- \sin 5\theta\left(\frac{a^4}{128} + \frac{5a^6}{1024}\right) \\ &- \sin 7\theta\left(\frac{a^6}{1024}\right)\end{aligned}$$

Omitting terms containing powers of a greater than the first

$$\sin(\theta+\varphi) = \sin\theta + \sin 2\theta\left(\frac{a}{2}\right) \qquad (17)$$

Multiplying (16) and (17) we have

$$\begin{aligned}\left(\frac{d\varphi}{dt}\right)^2 \sin(\theta+\varphi) &= [a^2\sin\theta\,(1 - \sin^2\theta) \\ &\quad + \frac{a^3}{2}\sin 2\theta\,(1 - \sin^2\theta)]\,\omega^2 \\ &= \frac{\omega^2 a^2}{4}\left|\begin{array}{l} + \sin\theta. \\ + \sin 2\theta.\,(a) \\ + \sin 3\theta. \\ + \sin 4\theta.\,\left(\frac{a}{2}\right)\end{array}\right.\end{aligned}$$

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Multiplying the variable part of the moment by the constants we have

$$\frac{R}{g}\ \frac{\omega^2 . K . r^2 . a}{4}\ \left|\begin{array}{l} + \sin\theta \\ + \sin 2\theta\ (a) \\ + \sin 3\theta \\ + \sin 4\theta \left(\frac{a}{2}\right) \end{array}\right| \qquad (18)$$

The development of the turning moment due to F_3 is as follows:

$$\begin{aligned} \cos(\theta + \varphi) &= \cos\theta\cos\varphi - \sin\theta\sin\varphi \\ &= \cos\theta\,(1 - a^2\sin^2\theta)^{\frac{1}{2}} - a\sin^2\theta \\ &= -\frac{a}{2} + \cos\theta\left(1 - \frac{a^2}{8} - \frac{a^4}{64} - \frac{25}{1024}a^6\right) \\ &\quad + \cos 2\theta\left(\frac{a}{2}\right) \\ &\quad + \cos 3\theta\left(\frac{a^3}{8} + \frac{3}{128}a^4 + \frac{9}{1024}a^6\right) \qquad (19) \\ &\quad - \cos 5\theta\left(\frac{a^4}{128} + \frac{7\,a^6}{1024}\right) \\ &\quad - \cos 7\theta\left(\frac{a^6}{1024}\right) \end{aligned}$$

From equation (15) we have

$$\frac{d^2\varphi}{dt^2} = \omega^2\ \left|\begin{array}{l} -\sin\theta\,(a + \frac{a^3}{8} + \frac{3}{64}a^5 + \ldots\ldots) \\ +\sin 3\theta\,(+\frac{3\,a^3}{8} + \frac{27}{128}a^5 + \ldots) \\ -\sin 5\theta\,(+\frac{75}{640}a^5 + \ldots\ldots\ldots) \end{array}\right| \qquad (20)$$

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Multiplying (19) and (20) together we have

$$\frac{d^2\varphi}{dt^2}\cos(\theta+\varphi) = \frac{\omega^2}{2}\left|\begin{array}{l} +\sin\theta\left(\frac{3a^2}{2}+\frac{3a^4}{8}+\frac{45}{256}a^6\right) \\ +\sin 2\theta\left(-a+\frac{a^3}{2}+\frac{24}{128}a^5\right) \\ -\sin 3\theta\left(\frac{a^2}{2}+\frac{7a^4}{16}+\frac{375}{1280}a^6\right) \\ +\sin 4\theta\left(\frac{a^3}{4}+\frac{5a^5}{640}\right) \\ +\sin 5\theta\left(\frac{3a^4}{16}+\frac{285}{1280}a^6\right) \\ -\sin 6\theta\left(\frac{45a^5}{640}\right) \\ -\sin 7\theta\left(\frac{75a^6}{1280}\right) \end{array}\right| \quad (21)$$

Neglecting the higher powers of a

$$\frac{d^2\varphi}{dt^2}\cos(\theta+\varphi) = -\frac{\omega^2 a}{2}\sin 2\theta \quad (22)$$

Supplying the constants in equation (8) we have

$$+\frac{R}{g}\,.\,d\,.\,\frac{\lambda}{l}\,.\,r\,.\,\frac{\omega^2 a}{2}\sin 2\theta \quad (23)$$

Calling the moment of inertia of the rod about the wrist pin I, we substitute it for $R\,d\,\lambda$ and have finally for the turning moment due to the force F

$$\frac{I\ \omega^2 a^2}{2\,g}\sin 2\theta \quad (24)$$

The moment of inertia about a parallel axis is $I = I_c + d^2 R$ where I_c is the moment of inertia about the center of gravity.

Equation (24) may therefore be written

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$$\frac{I\,\omega^2\,a^2}{2\,g}\sin 2\,\theta = \frac{I_c\,\omega^2\,a^2}{2\,g}\sin 2\,\theta + \frac{R\,d^2\,\omega^2\,a}{2\,g}\sin 2\,\theta$$

$$= I_c\,\frac{\omega^2\,a^2\sin 2\,\theta}{2\,g} + \frac{R\,K^2\,\omega^2\,r^2}{2\,g}\sin 2\,\theta$$

The turning moments due to F_1, F_2 and F_3 are:
for F_1

$$\frac{R}{g}\omega^2 r^2(1-K)\left|\begin{array}{l} +\sin\theta\left(\frac{a}{4}+\frac{a^3}{16}+\frac{45\,a^5}{492}\right) \\ -\sin 2\,\theta\,(1-K)\left(-\frac{a^4}{64}+\frac{510\,a^6}{7680}\right) \\ -\sin 3\,\theta\left(\frac{3\,a}{4}+\frac{3\,a^3}{16}+\frac{165\,a^5}{512}\right) \\ -\sin 4\,\theta\,(1-K)\left(\frac{a^2}{4}+\frac{5\,a^4}{64}+\frac{448\,a_6}{3072}\right) \\ +\sin 5\,\theta\left(\frac{5\,a^3}{32}+\frac{105\,a^5}{512}\right) \end{array}\right| - \frac{R}{g}\omega^2 r^2\sin 2\theta\tfrac{1}{2}$$

for F_2, $-\frac{R}{g}\cdot\frac{\omega^2\,K\,r^2\,a}{4}\left|\begin{array}{l} +\sin\theta \\ +\sin 2\,\theta\,(a) \\ +\sin 3\,\theta \\ +\sin 4\,\theta\left(\frac{a}{2}\right) \end{array}\right|$

$$\text{for } F_3,\quad I_c\,\frac{\omega^2\,a^2\sin 2\,\theta}{2\,g} + \frac{R\,K^2\,\omega^2\,r^2\sin 2\,\theta}{2\,g}$$

The turning moment of the rod is the sum of the separate moments. Neglecting the term sin 2 θ in the parenthesis, for the turning moment of F_1, adding the term outside to the second term of F_3, and rearranging the terms in F_2, we have finally:

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$$\frac{R}{g} \cdot \omega^2 r^2 (1 - K) \left| \begin{array}{l} + \sin \theta \left(\frac{a}{4} + \frac{a^3}{16} + \frac{45\, a^5}{492} \right) \\ - \sin 2\theta \left(\frac{1 + K}{2} \right) \\ - \sin 3\theta \left(\frac{3\, a}{4} + \frac{3\, a^3}{16} + \frac{165\, a^5}{512} \right) \\ - \sin 4\theta (1 - K) \left(\frac{a^2}{4} + \frac{5\, a^4}{64} + \frac{448\, a^6}{3072} \right) \\ + \sin 5\theta \left(\frac{5\, a^3}{32} + \frac{105\, a^5}{512} \right) \end{array} \right|$$

$$- \frac{k'}{g} \cdot \omega^2 r^2 (1 - K) \left| \begin{array}{l} + \sin \theta \, \frac{K a}{4 (1 - K)} \\ + \sin 2\theta \left(\frac{K a^2}{4 (1 - K)} \right) \\ + \sin 3\theta \, \frac{K a}{4 (1 - K)} \\ + \sin 4\theta \, \frac{K a^2}{8 (1 - K)} \end{array} \right| + I_c \frac{\omega^2 a^2 \sin 2\theta}{2 g} \qquad (25)$$

Part II.

The apparatus employed was a tuning fork electrically driven by a storage battery and a paper band secured to the face of the fly-wheel of the tandem engine before mentioned. Description of apparatus employed is as follows:

The Tuning Fork.—The tuning fork was made by Queen & Co. and was fitted with phosphor bronze fingers in order to increase the amplitude. It was driven by a storage battery and the usual make and break device employed. The period of the fork without the fingers was 100 per second, and with the fingers when in contact with the paper band 90. Care was taken in adjusting the fingers that the points would describe the same line on the paper when the wheel was revolved and the fork at rest.

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To Further Explain.—When the fork is at rest and the wheel revolved the points described the line A B, and when the fork vibrated the points described the lines C D and E F. Assuming the fork's period constant, the distance between intersections 1 and 3 is the space travelled by the wheel in one complete vibration of the fork. The amplitude of the vibrations was 7 mms. The fork was mounted upon a slide rest, which was securely fastened to the floor. The fork, therefore, could be moved across the face of the wheel, the slide being in parallelism with the face of the wheel.

The Paper Band.—In order to have a smoother surface for the fingers of the fork to trace the curves and to facilitate the measurements, manila paper with a smooth surface was used. The paper may be obtained in rolls 12″ or more wide and of considerable length. The paper was secured to the face of the wheel by shellac varnish applied at the edges, and the joint was scarfed and secured by shellac varnish. Considerable care was

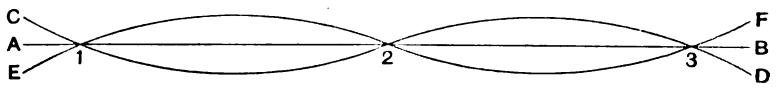

FIG. 3.

taken to avoid wrinkles. The paper was then slightly moistened with water applied with a paint brush. On drying it was found the surface was without wrinkles and smooth. Zinc paint, made by mixing zinc oxide ground in oil with spirits of turpentine, was applied to the paper with a paint brush. It is well known that silver, copper and brass will mark upon a surface coated as above.

After the wheel was prepared as described, the engine was put on its head center, corresponding to $\theta = 0$ in the theoretical part, and the tuning fork moved across the face, the points of the fingers describing two lines. This fixed the positions of all the tuning fork spaces relative to the crank positions.

THE TEST.

An artificial full load was put upon the generator by means of a water rheostat which consisted of iron plates immersed in a dock. Owing to the large amount of water the load was con-

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stant. The ampere flow was 1,440 at 562 volts. I have carried on the same plates 3,400 amperes at 550 volts. After the engine had been running some time at this and lower loads in order that it might be thoroughly warmed, simultaneous readings of amperes and volts, indicator diagrams and record by the tuning fork were taken.

The running weights of the tandem engine were estimated as follows:

Low pressure piston	1,900	lbs.
High " "	500	"
Crosshead	1,200	"
Connecting rod	1,900	"
Piston rod	1,000	"

Length of connecting rod between centers 126″.
Crank radius, 21″.

$$\frac{r}{l} = a = 1/6$$

Moment of inertia of rod about its center of gravity approximately $9.402\ R\ r^2$

$$K = 0.6$$

Substituting in equation (25)

We have for the turning moment of the rod

$$\frac{R}{g}\ \omega^2\ r^2\ [-\sin\theta\ 0.0082 - \sin 2\theta\ 0.1934 \cdot$$

$$-\sin 3\theta\ 0.0755 - \sin 4\theta\ 0.00316]$$

Substituting in equation (4)

We have turning moment of the reciprocating parts

$$\frac{M}{g}\ \omega^2\ r^2 \left| \begin{array}{l} +\sin\ \theta\ 0.04204 \\ -\sin 2\theta\ 0.50000 \\ -\sin 3\theta\ 0.12648 \\ -\sin 4\theta\ 0.00695 \end{array} \right|$$

Speed of engine 96 R.P.M., or 10.05 radians per second; $\omega_2 = 101$.

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From the above data Table I has been constructed. Ordinates in inches on a scale of 20,000 pounds per inch are given for the reciprocating parts M and for the rod R. The resultant ordinate is also given, so it is possible to plot the curves of turning moments of the total inertia forces or the parts separately.

The steam pressures are obtained from the indicator diagrams Table II, and the forces acting along the piston rod are given in Table III.

Equation (3) gives the turning moment due to the steam forces, and Table IV is the part within the parenthesis.

The second column of Table V gives the ordinates of the steam turning moments which are obtained by multiplying the last column of Table III (P), with the last column of Table IV together with the crank radius and dividing the product by the scale used, 20,000 pounds per inch.

The third column of Table V is obtained from Table I, and the fourth column is the algebraic sum which is the ordinate of the curve plotted.

The Curves.

Curve A is the curve obtained from the plotted values, and represents according to proper scale which is given, the turning moment at crank shaft center, the tangential force at crank pin, the acceleration at crank pin, or the acceleration at fly-wheel rim.

Considering it as a curve of acceleration at fly-wheel rim and integrating the area intercepted between the mean line (or curve of no acceleration) the curve and ordinates and plotting the values the curve of velocity variation is constructed, curve B. Proceeding in the same manner curve C is constructed which is the space variation.

Tables VI, VII, VIII, IX, give the measured values of four curves, which constitute four consecutive revolutions. Column I contains the numbers of the spaces described by the tuning fork in one period. The spaces are numbered consecutively, beginning at the head center or "0" angle. Column II shows the measurements of the spaces. Column III gives the average value of three consecutive measurements, for example, the value of the first space is the mean of the sum of measurements of the fifty-sixth, first and second spaces. The value of the second space is the mean of the sum of the measurements of the first, second and third spaces, and so on.

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Column IV is formed by adding the second average value to the first for the value opposite the second space, the third to the second for the third space, and so on. Column IV shows the actual distance traveled by the wheel for any number of periods.

Column V is formed by taking the mean of the sum of average values in Column III, and setting them down as in Column IV. Column V shows the space traveled by a wheel rotating uniformly for any number of periods.

Column VI is formed by taking the first differences between Columns IV and V, and shows the actual space variation between a wheel rotating with constant angular velocity and one rotating with variable angular velocity.

An inspection of the curves shows a space variation of about 11 mms., whereas the calculated space variation is 7 mms. I am not prepared to say that this difference is caused by errors or by some lost motion, probably, the former, possibly both.

A fork having greater amplitude and higher period marking upon a smoother surface would undoubtedly give more accurate results. If, however, the information of this most interesting problem has been increased by this contribution its object has been fulfilled.

In conclusion, I desire to express my thanks to Mr. J. M. S. Waring, who has assisted me, and to whose efforts and patience too much praise cannot be given. I desire to thank also Mr. Harte Cooke and others for advice and assistance.

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TABLE I.

	15°		30°		45°		60°		75°		90°		105°		120°		135°		150°		165°	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	
+ .042 sin θ...	.0168		.0210		.0298		.0363		.0405		.042		.0405		.0363		.0298		.0210		.0108	
− .500 sin 2 θ..		.25		.433		.5		.433		.25			.25		.433		.5		.433		.25	
− .127 sin 3 θ..		.09		.127		.09			.09		.127		.09					.09		.127		.09
− .007 sin 4 θ..		.0061		.0061			.0061		.0061					.0061		.0061			.0061		.0061	
Totals.....	.0168	.3461	.0210	.5661	.0298	.59	.0424	.433	.1366	.25	.169		.3805	.0061	.4693	.0061	.5298	.09	.4601	.127	.2669	.09
Sums.....		.3353		.5451		.5602		.3906		.1134	.169		.3744		.4632		.4398		.4331		.1769	
$\frac{M\omega^2 r^2}{g} = \frac{44000}{20000}$		.736		1.10		1.235		.860		.25	.372		.826		1.02		0.966		.952		.390	
− sin θ .0082...		.00212		.00410		.00578		.0071		.00792		.0082		.00792		.0071		.00578		.0041		.00212
− sin 2 θ .1934.		.09670		.16730		.1934		.167		.09670			.09670		.1673		.1934		.1673		.0967	
− sin 3 θ .0755..		.05330		.07550		.0533			.0533		.0755		.0533					.05330		.0755		.0533
− sin 4 θ .0032		.00270		.00270			.0027		.0027					.00270		.0027			.0027		.0027	
Totals.....		.15482		.24960		.25248	.0027	.1742	.0560	.10402	.0755	.0082	.1500	.01062	.1673	.0098	.1934	05908	.1700	.0796	.0994	.055 2
Sums		.15482		.24960		.25248		.1715		.04862	.0673		.13938		.1575		.13432		.0904		.04398	
$\frac{R\omega^2 r^2}{g} = \frac{18200}{20000}$		.141		.227		.230		.156		.044	.061		.127		.144		.122		.0823		.04	
R + M		.877		1.327		1.465		1.016		0.294	0.433		0.953		1.164		1.088		1 034		0.43	

TABLE II.

Crank positions	0	1	2	3	4	5	6	7	8	9	10	11	12
	24	23	22	21	20	19	18	17	16	15	14	13	
H. P. Head....	130	127	126	123	122	98	73	61	51	44	41	38	33
	114	84	46	22	13	24	15	15	16	17	19	25	
H. P. Crank....	38	42	54	61	71	90	114	127	127	127	126	126	126
	22	20	17	17	17	16	15	15	19	33	54	88	
L. P. Head....	15	15	15	14.75	14.5	11.75	5 5	2.5	0.5	— 1.0	— 2.25	— 4.0	— 5.0
	1	— 3.75	— 8.25	— 8.25	— 8.25	— 8.0	— 8.0	— 8.0	— 8 0	— 8.0	— 7.75	— 7.0	
L. P. Crank....	— 4.5	— 3.25	— 1.75	0	2.0	5.0	10.75	12 5	14.0	14.25	14.50	12 0	9.0
	6.0	— 7.0	— 8.0	— 8.5	8 5	— 8.75	— 9.0	— 9.0	— 9.0	— 9.0	— 9.0	— 7.0	

SHEET No. 1.

TANDEM COMPOUND ENGINE.

24–45–42.

Weight fly-wheel rim	56,000 lbs.	Radius of gyration	7,584 ft.
" " spokes	17,100 "	" "	4.500 "
" crank disc	8,000 "	" "	2,000 "
" armature	45,000 "	" "	3,000 "

Stroke of engine, 42 ins.

The above weights reduced to the crank center:

Fly-wheel rim	1,070,000 lbs.
" spokes	113,000 "
Crank disc	10,450 "
Armature	132,500 "
Total	1,325,950 lbs.

CURVE No. 1.

Horizontal scale, $1'' = 60 \div (100 \times 24) = 0.025$ secs.

" " $1'' = (3.5 \times \pi) \div 24 = 0.460$ ft.

Turning moment at crank shaft center:

Vertical scale, $1'' = 20{,}000$ ft. lbs.

Tangential force at crank pin:

Vertical scale, $1'' = 20{,}000 \div 1.75 = 11{,}420$ lbs.

Acceleration at crank pin:

Vertical scale, $1'' = (11{,}420 \times 32.2) \div 1{,}325{,}950 = 0.278$ ft. per sec.

Acceleration at fly-wheel rim:

Vertical scale, $1'' = (0.278 \times 16) \div 3.5 = 1.27$ ft. per sec.

Areas, 1 sq. in. $= 11{,}420 \times 0.46 = 5{,}260$ ft. lbs.

CURVE No. 2

Vertical scale, $1'' = 1.27 \times 2 \times 0.025 = 0.0635$ ft. per sec. at fly-wheel rim.

Maximum ordinate, 4.44 ins.

Totol velocity variation, $4.44 \times .0635 = 0.282$ ft. per sec.

Mean velocity, 83.75 ft. per sec.

Percentage of mean velocity, 0.00337.

Coefficient of unsteadiness, 296.

CURVE No. 3.

Vertical scale, $1'' = 0.0635 \times 2 \times .025 = 0.00317$ ft. at fly-wheel rim.

Maximum ordinate, 5.125 ins.

Total space variation, $5.125 \times .00317 = 0.0162$ ft.
$= 0.1945$ ins.

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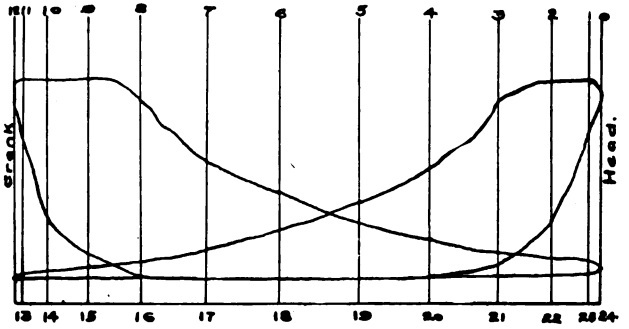
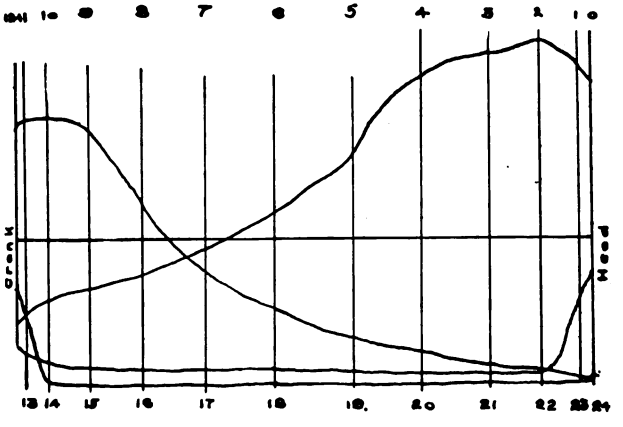
Crank pos.	0	1	2	3	4	5	6	7	8	9	10	11	12
" "	24	23	22	21	20	19	18	17	16	15	14	13	12
L.P Head	10¼	12	13	12	10¼	5¼	1½	-1	-2½	-3½	-4	-6	-6¼
" "	-2¼	-4½	-9	-9	-9	-9	-9	-9	-9	-8½	-8	-7½	-7
" Crank	-9½	-9½	-9	-8½	-7½	-6½	-4½	-2	3	7½	8	8	8
" "	-9½	-10	-10	-10	-10	-10	-10	-10	-10	-10	-9½	-5	-3
H.P. Head	114	120	120	108	73.5	55	44.6	31.2	24	20.8	18.2	16.8	16
" "	108	92	47.2	22.6	14.4	14.4	16	16	16	16	16	16	16
" Crank	22.4	23.2	26.5	28.6	34.4	46.4	62.2	78.2	112	120	120	120	120
" "	18.4	16.8	16.0	16.0	15.2	14.4	14.4	14.4	14.4	28	46.4	92	106



80 lb. Spring



10 lb. Spring

Sheet No. 1.

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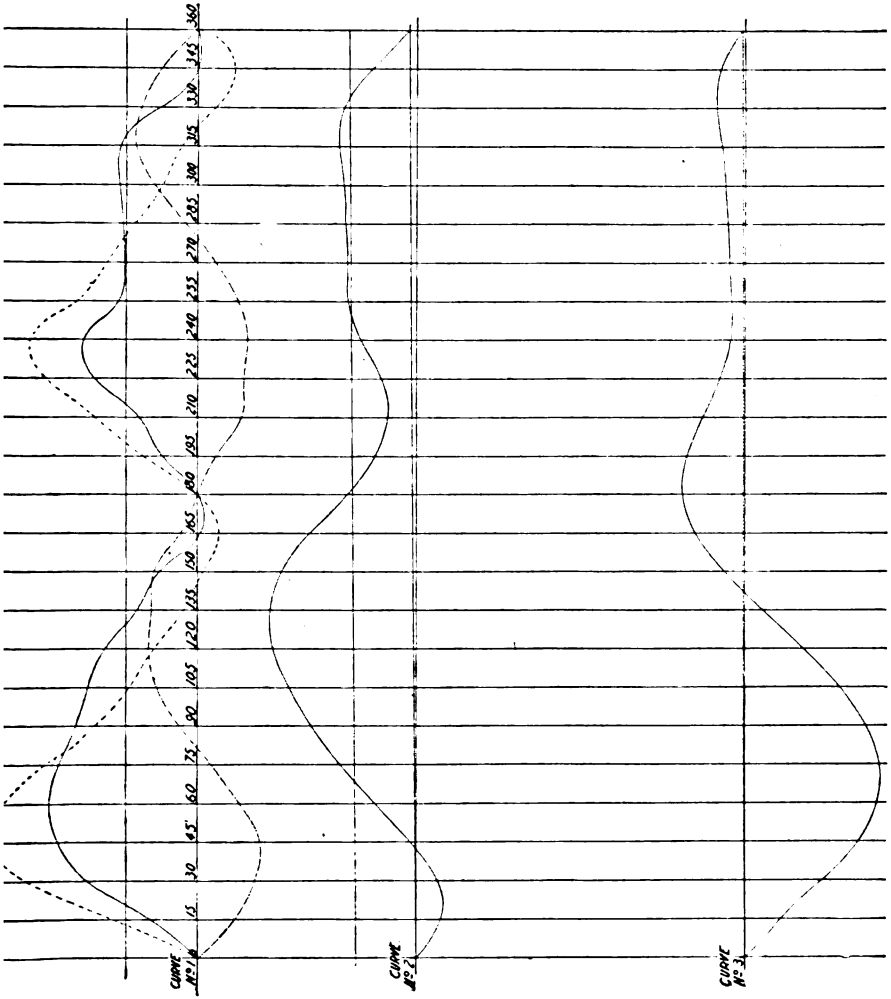

Sheet No. 1.

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TABLE III.

	H. P. Head	H. P. Crank	L. P. Head	L. P. Crank	H. P.	L. P.	Combined
0	58900	16600	15745	—7030	49300	25120	74420
1	57500	18350	23600	—5075	48760	34530	83290
2	57000	23600	23600	—2735	49570	36100	85670
3	55600	26600	23200	0	48170	36500	84670
4	55200	31000	22900	3123	47770	36200	83970
5	44400	39300	18500	7820	37410	32200	69610
6	33000	49800	8675	16980	26450	22735	49185
7	27600	55500	3940	19550	21050	18000	39060
8	23100	55500	790	21900	14800	14850	29650
9	19900	55500	—1575	22280	5500	12485	17985
10	18550	55100	—3550	22650	—5050	10510	5460
11	17300	55100	—6310	18750	—21200*	4620	—16580
12	14900	55100	—8675	14070	—40200	—22745	—62945
13	11300	38400	—11000	—10930	43800	29750	73550
14	9600	23600	—12200	—14060	46500	34850	81350
15	7700	14400	—12600	—14060	47800	34880	82680
16	7240	8300	—12600	—14060	48260	34500	82760
17	6790	6550	—12600	—14060	48710	32150	80860
18	6790	6550	—12600	—14060	48010	29400	72410
19	6330	6990	—12600	—18700	32970	20420	53390
20	5880	7430	—13000	—13300	25120	16123	41243
21	9950	7430	—13000	—13300	16650	13000	29650
22	20800	7430	—13000	—12500	2800	10265	13065
23	38000	8740	—5920	—10930	—19650	845	—18805
24	51600	9600	1575	—9375	—35000	—8605	—43605

NET AREAS

H. P. Head	452.4 sq. ins.	L. P. Head	1574.53
H. P. Crank	436.5 " "	L. P. Crank	1562.16

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SHEET No. 2.

TANDEM COMPOUND ENGINE.

24–45–42.

Weight fly-wheel rim	56,000 lbs.	Radius of gyration	7,584 ft.
" " spokes	17,100 "	" "	4,500 "
" crank disc	8,000 "	" "	2,000 "
" armature	45,000 "	" "	8,000 "

Stroke of engine, 42 ins.

The above weights reduced to the crank center:

Fly-wheel rim	1,070,000 lbs.
" spokes	113,000 "
Crank disc	10,450 "
Armature	132,500 "
Total	1,325,950 lbs.

CURVE "A."

Horizontal scale, $1'' = 60 \div (96 \times 24) = 0.026$ secs.

" " $1'' = (3.5 \times \pi) \div 24 = 0.460$ ft.

Turning moment at crank shaft center:

Vertical scale, $1'' = 20{,}000$ ft. lbs.

Tangential force at crank pin:

Vertical scale, $1'' = 20{,}000 \div 1.75 = 11{,}420$ lbs.

Acceleration at crank pin:

Vertical scale, $1'' = (11{,}420 \times 32.2) \div 1{,}325{,}950 = 0.278$ ft. per sec.

Acceleration at fly-wheel rim:

Vertical scale, $1'' = (0.278 \times 16) \div 3.5 = 1.27$ ft. per sec.

CURVE "B."

Vertical scale, $1'' = 1.27 \times 2 \times 0.026 = 0.066$ ft. per sec. at fly-wheel rim.

Maximum ordinate, 5.84 ins.

Total velocity variation, $5.84 \times 0.066 = 0.385$ ft. per sec.

Mean velocity, 80.4 ft. per sec.

Percentage of mean velocity, 0.00479.

Coefficient of unsteadiness, 209.

CURVE "C."

Vertical scale, $1'' = 0.066 \times 2 \times 0.026 = 0.00343$ ft. at fly-wheel rim.

Maximum ordinate, 6.67 ins.

Total space variation, $6.67 \times 0.00343 = 0.0229$ ft.

$= 0.2748$ ins.

$= 6.9750$ mms.

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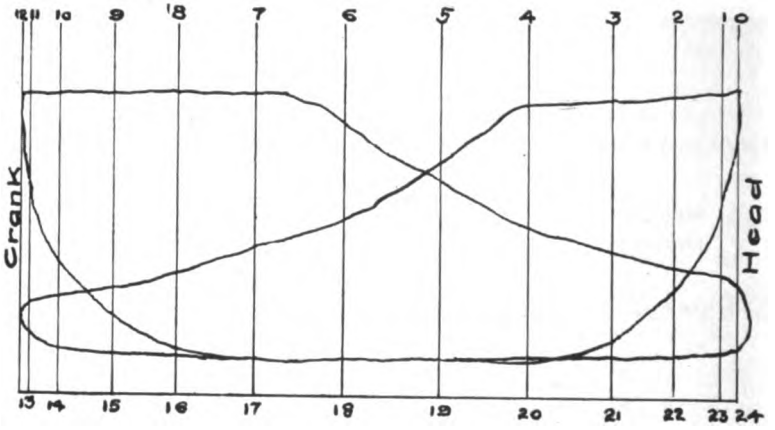
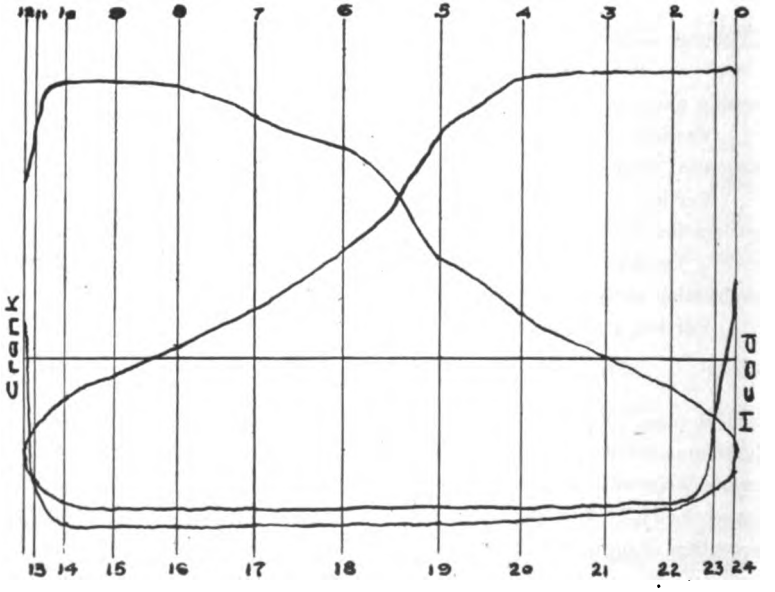


80 lb. Spring



10 lb. Spring

Sheet No. 2.

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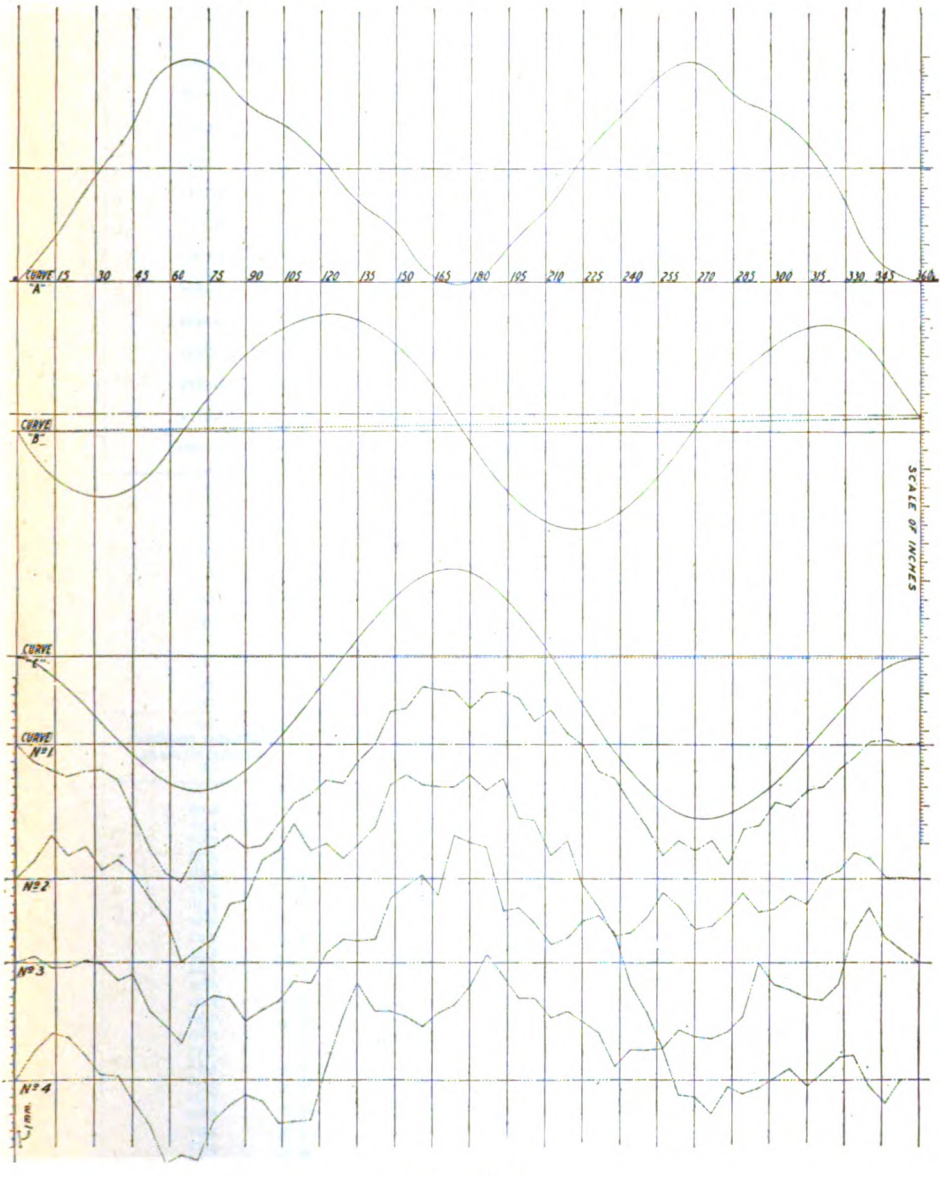

Sheet No. 2.

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TABLE IV.

Angle.	$\sin \theta$	$\sin 2\theta \frac{a}{2}$	$\sin \theta + \sin 2\theta \frac{a}{2}$
0	0.000	0.0000	0.0000
15	0.259	0.0416	0.3006
30	0.500	0.0721	0.5721
45	0.707	0.0833	0.7903
60	0.866	0.0721	0.9381
75	0.966	0.0416	1.0076
90	1.000	0.0000	1.0000
105	0.966	— 0.0416	0.9244
120	0.866	— 0.0721	0.7939
135	0.707	— 0.0833	0.6237
150	0.500	— 0.0721	0.4279
165	0.259	— 0.0416	0.2174
180	0.000	0.0000	0.0000

TABLE V.

Crank Positions.	Ordinates steam turning moments.	Ordinates inertia turning moments.	Ordinates resultant turning moment.
0	0.00	0.00	0.00
1	2.18	— 0.88	1.30
2	4.28	— 1.33	2.95
3	5.83	— 1.47	4.36
4	6.90	— 1.02	5.88
5	6.10	— 0.29	5.81
6	4.30	+ 0.43	4.76
7	3.15	+ 0.95	4.10
8	2.05	+ 1.17	3.22
9	0.98	+ 1.09	2.07
10	0.21	+ 1.03	1.24
11	— 0.32	+ 0.43	0.11
12	0.00	0.00	0.00
13	1.39	— 0.43	0.96
14	3.06	— 1.03	2.03
15	4.52	— 1.09	3.43
16	5.75	— 1.17	4.58
17	6.51	— 0.95	5.56
18	6.35	— 0.43	5.92
19	4.73	+ 0.29	5.02
20	3.40	+ 1.02	4.42
21	2.05	+ 1.47	3.52
22	0.65	+ 1.33	1.98
23	— 0.50	+ 0.88	0.38
24	0.00	0.00	0.00

Ordinates in inches. Scale, 20,000 lbs. per inch.

Note.—Mean ordinate of resultant turning moment 3.06", by Simpson's Rule.

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Table VI.

Curve No. 1

I	II	III	IV	V	VI
0	27.30	26.96	26.96	27.06	−0.10
1	26.80	27.02	53 98	54.13	−0.15
2	26.95	27.02	81.00	81.19	−0.19
3	27.32	27.09	108.09	106.25	−0.16
4	26.99	27.08	135 17	135.32	−0 15
5	26.93	26.99	162.16	162 37	−0.21
6	27.05	26.87	189.03	189.44	−0.41
7	26.68	26.85	215.88	216.50	−0.62
8	26.88	26.92	242.80	243.57	−0.77
9	27.25	27.01	269.81	270.63	−0.82
10	26.90	27.25	297.06	297.69	−0.63
11	27.60	27.09	324.15	324.76	−0.61
12	26.78	27.13	351.28	351.82	−0.54
13	27.00	26.98	376.26	378.88	−0.62
14	27.15	27.09	405.35	405.95	−0.60
15	27.11	27.19	432.54	433.01	−0.47
16	27 30	27.18	459.72	460.07	−0.35
17	27.12	27.12	486.84	487.14	−0.30
18	26.93	27.15	513.99	514.20	−0.21
19	27.40	27.04	541.03	541.26	−0 23
20	26.78	27.20	568.23	568.33	−0.10
21	27.42	27.16	595 39	545.39	±0.00
22	27.26	27.26	622.65	622 45	+0.20
23	27.08	27.09	649.74	649.52	+0.22
24	26.92	27.19	676.93	676.58	+0.35
25	27.57	27.04	703.97	703.64	+0.33
26	26.62	27.05	731.02	730.70	+0.32
27	26.96	26.97	757.99	757.77	+0.22
28	27.32	27.15	785.14	784.83	+0.31
29	27.18	27.07	812.21	811.89	+0 32
30	26 70	27.03	839.24	838.96	+0.28
31	27.20	26.92	866.16	866.02	+0.14
32	26.85	27.13	893.29	893.08	+0.21
33	27.35	26.93	920.22	920.15	+0.07
34	26.59	26.99	947.21	947.21	±0.00
35	27.04	26.90	974.11	974.27	−0.16
36	27.08	27.02	1001.13	1001.33	−0.20
37	26.95	26.91	1028.04	1028.39	−0.35
38	26.70	26.93	1054.97	1055.46	−0.49
39	27.15	26.90	1081.87	1082.53	−0.66
40	26.85	27.15	1109.02	1109.59	−0.57
41	27.45	27.00	1136.02	1136.65	−0.63
42	26.70	27.12	1163 14	1163.71	−0.57
43	27.22	26.93	1190.07	1190.78	−0.71
44	26.88	27.27	1217.34	1217.84	−0.50
45	27.10	27.08	1244.42	1244.90	−0.48
46	26.65	27 21	1271.63	1271.97	−0.34
47	27.27	27.03	1298.66	1299 03	−0.37
48	27.18	27.16	1325.82	1326.09	−0 27
49	27 03	27.09	1352.91	1353.16	−0.25
50	27.07	27.17	1380 06	1380.22	−0.14
51	27.42	27.13	1407.21	1407.28	+0.07
52	26.90	27.16	1434.37	1434.35	+0.02
53	27.16	27.07	1461.44	1461.41	+0.03
54	27.16	27.03	1488.47	1488.47	±0.00
55	26.78	27.08	1515.55	1515.54	+0.01

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Table VII.

Curve No. 2

I	II	III	IV	V	VI
0	27.25	27.18	27.18	27 07	+0.11
1	27.18	27.23	54 41	54.14	+0 27
2	27.25	26.94	81.35	81 21	+0.14
3	26.40	27.13	108.48	108.29	+0.19
4	27.73	26 93	135 41	135.36	+0.05
5	26.65	27.13	162.54	162 43	+0.11
6	27 00	26.99	189.53	189.50	+0.03
7	27.33	26.92	216.45	216 57	−0.12
8	26.42	26 95	243.40	243.64	−0.24
9	27.10	26 82	270.22	270.71	−0.50
10	26.95	27.14	297.36	297.79	−0.42
11	27.38	27.14	324.50	324.86	−0.36
12	27.10	27.28	351.78	351.93	−0.15
13	27.35	27.09	378.87	379.00	−0.13
14	26 82	27.31	406.18	406.07	+0.11
15	27.75	27.14	433.32	433.15	+0.17
16	26.65	27.23	460.55	460 22	+0.33
17	27.30	26.91	487.46	487.29	+0.17
18	26.78	27.11	514.57	514 36	+0.21
19	27.25	26.98	541 55	541 43	+0.12
20	26.90	27 15	568.70	568.50	+0.20
21	27 30	27.18	595.88	595 58	+0.31
22	27.35	27.32	623 20	622.65	+0.56
23	27 30	27.14	650.34	649 72	+0.62
24	26.78	27.01	677.35	676.79	+0.56
25	26.95	27.06	704.41	703.86	+0 55
26	27.45	27.07	731.48	730.93	+0.55
27	26.80	27.14	758.62	758.00	+0.62
28	27.18	26.99	785.61	785.08	+0.53
29	27.00	27.14	812.75	812.15	+0.60
30	27.23	26.84	839.59	839.22	+0.37
31	26.30	27.05	866.64	866.29	+0.35
32	27.02	26.86	893.50	893.36	+0.14
33	26.65	27.16	920.66	920.43	+0.23
34	27.20	26.82	947.48	947.51	−0.03
35	26.60	26 93	974.41	974.58	−0.17
36	27.00	26.90	1001.31	1001.65	−0.34
37	27.10	27.09	1028.40	1026.72	−0.32
38	27.17	27.16	1055.56	1055.79	−0.23
39	27.20	27.22	1082.78	1082.86	−0.08
40	27.28	26.99	1109.77	1109.94	−0.16
41	26.50	26.94	1136.71	1137.01	−0.30
42	27.05	27.09	1163.80	1164.08	−0.28
43	27.73	27.16	1190.96	1191.15	−0 19
44	26.70	27.18	1218.14	1218.32	−0.08
45	27.12	26.95	1245.09	1245 29	−0.20
46	27 03	27.10	1272.19	1272.37	−0.18
47	27.15	27.15	1299.34	1299.44	−0.10
48	27.28	27.02	1326 36	1326.51	−0.15
49	26.63	27.22	1353.58	1353.58	±0.000
50	27.75	27.12	1380.70	1380.65	+0.05
51	26.98	27.18	1407 88	1407.72	+0.16
52	26.80	27.03	1434.91	1434.79	+0.16
53	27.30	26.97	1461.88	1461.87	+0.01
54	26.80	27.07	1488.95	1486.94	+0.01
55	27.12	27.06	1516.01	1516.01	±0.000

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Table VIII.

Curve No. 8

I	II	III	IV	V	VI
0	27.00	27.09	27.09	27 05	+0.04
1	26.80	26.97	54.06	54.09	−0.03
2	27 12	27.05	81.11	81.14	−0.03
3	27.22	27 08	108 19	108.18	+0.01
4	26 70	27.03	135.22	135.23	−0.01
5	27.18	26 94	162.16	162.27	−0.11
6	26 95	27.09	189.25	189.32	−0.07
7	27 13	26.82	216.07	216.36	−0.29
8	26.37	26.96	243.03	243.41	−0.38
9	27.38	26 95	269 98	270.46	−0 48
10	27.10	27 26	297.24	297 50	−0 26
11	27.30	27.11	324.35	325.55	−0 20
12	26.93	27.02	351.37	351 59	−0.22
13	26.82	26.92	378.29	378.64	−0.35
14	27.00	27.11	405 40	405 68	−0.28
15	27.50	27.10	432.50	432.73	−0.23
16	26 80	27.17	459 67	359.76	−0.11
17	27.20	27.03	486 70	486.82	−0.12
18	27.08	27.23	513 90	513.87	+0 06
19	27.42	27 12	541.05	540.91	+0.14
20	26 85	27.04	568 09	567.96	+0.13
21	26.85	27 05	595 14	595 00	+0.14
22	27.45	27 30	622.44	622.05	+0.39
23	27.60	27.11	649.55	649 09	+0.46
24	26.27	27.11	676.66	676.14	+0.52
25	27.47	26.93	703.59	703.19	+0.40
26	27.05	27.40	730.99	730.23	+0.76
27	27.67	26.91	757.90	757.28	+0.72
28	26.00	27.01	784.91	784 32	+0 69
29	27.35	26.77	811 68	811.37	+0.31
30	26.97	27.06	838.74	838 41	+0.33
31	26.85	26.96	865.70	865.46	+0.24
32	27.05	26.91	892.61	892.50	+0 11
33	26.83	27.09	919.70	919 55	+0.15
34	27.40	27.15	946 85	946.60	+0.25
35	27.22	27.07	973.92	973.64	+0.28
36	26.60	26.95	1000.87	1000.69	+0 18
37	27.02	26.73	1027.60	1027.73	−0.13
38	26.58	26 88	1054.48	1054.78	−0.30
39	27.02	26 83	1081.31	1081.62	−0 51
40	26.90	27.16	1108 47	1108-87	−0.40
41	27.55	27.01	1135.48	1135.92	−0 44
42	26.58	27.03	1162.51	1162.96	−0.45
43	26.95	27 09	1189.60	1190.01	−0.41
44	27.75	27.13	1216.72	1217.05	−0.32
45	26.70	27 37	1244.10	1244.10	±0.000
46	27.65	26.91	1271.01	1271.14	−0.13
47	26.37	27.02	1298.03	1298.19	−0.16
48	27.05	26.99	1325.02	1325.33	−0.21
49	26.55	27.04	1352.06	1352.28	−0 22
50	27.52	27.14	1379.20	1379 33	−0.13
51	27.35	27.35	1406.55	1406 37	+0.18
52	27.17	27.19	1433 74	1433.42	+0.33
53	27.05	26.87	1460.61	1460.46	+0.15
54	26.40	26.98	1487.59	1487.50	+0.08
55	27.48	26.96	1514.55	1514.55	±0.00

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Table IX.

Curve No. 4

I	II	III	IV	V	VI
0	27.12	27 21	27.21	27.03	+0.18
1	27.12	27.13	54.34	54.06	+0 28
2	27.15	26.99	81.33	81 08	+0.25
3	26 70	26.92	108 25	108.11	+0.14
4	26.92	26.92	135.17	135 14	+0.03
5	27.13	27 02	162.19	162.17	+9 02
6	27.00	26.88	189.07	189.20	−0.13
7	26.52	26.87	215.94	216 22	−0.28
8	27.10	26.81	242.75	243.25	−0.50
9	26.80	27.08	269.83	270.28	−0.45
10	27.35	27.00	296.83	297.31	−0.48
11	26.85	27 27	324.10	324.34	−0.24
12	27.60	27.11	351.21	351.36	−0.15
13	26 98	27.09	378.30	378.39	−0.09
14	26.80	26.99	405.29	405.42	−0.13
15	27.30	26.90	432.19	432.45	−0.26
16	26.60	27.04	459 23	459.48	−0.25
17	27.22	27.03	486.26	486.50	−0.24
18	27.28	27.35	513.61	513.53	+0.08
19	27.55	27.33	540.94	540.56	+0.38
20	27.15	27.23	568.17	567 59	+0.58
21	27.00	26 96	595.13	594.62	+0.41
22	26.73	26.92	622.05	621 64	+0.41
23	27.03	27.00	640 05	648.67	+0.38
24	27.25	26.97	676.02	675.70	+0.32
25	26.63	27.11	703.13	702.73	+9.40
26	27.45	27.08	730.21	729.76	+0.45
27	27.15	27.13	757.34	756.78	+0 56
28	26.80	27.22	784.56	783 81	+0.75
29	26.70	26.00	811.46	810.84	+0.62
30	27 20	26.90	838 36	837.87	+0.49
31	26.80	27.03	865 39	864.90	+0.49
32	27.08	26.90	892.29	891 92	+0.37
33	26.82	27.07	919.36	918 95	+0.41
34	27.30	26.97	946.33	945.96	+0.35
35	26.78	26.96	973.29	973.01	+0.28
36	26.80	26 83	1000.12	1000.04	+0.08
37	26.90	27.12	1027.24	1027.06	+0.18
38	27.65	27.03	1054.27	1054.09	+0.18
39	26.55	27.04	1081.31	1081.12	+0.19
40	26.93	26.74	1108.05	1108 15	−0.09
41	26 75	27.03	1135.08	1135.18	−0 10
42	27.40	27.02	1162 10	1162.30	−0 20
43	26.90	27.09	1189.19	1189.23	−0.04
44	26.97	26.99	1216.18	1216.26	−0.08
45	27.10	27.06	1243.24	1243.29	−0.05
46	27.10	27.09	1270.33	1270.32	+0.01
47	27.08	27.08	1297.41	1297.34	+0 07
48	27.07	26 93	1324.34	1324 37	−0.03
49	26.65	27.10	1351.44	1351.40	+0 04
50	27.58	27.13	1378.57	1378.42	+0 14
51	27.15	27.04	1405.61	1405.46	+0.15
52	26.88	26.84	1432.45	1432 48	−0.03
53	27.00	26.92	1459.37	1459 51	−0 14
54	27.88	27.17	1486.54	1486.54	±0.000

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TABLE A.

Crank angles ...	0	0	15	15	30	30	45	45	60	60	75	75	90	90	105	105	120	120	135	135	150	150	165	165	180	180
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
+ .05 sin θ	0	0	.013		.025		.035		.044		.048		.05		.048		.044		.035		.025		.013		0	0
− .5 sin 2 θ	0	0		.25		.44		.50		.44		.25	0	0	.25		.44		.50		.44		.25		0	0
− .15 sin 3 θ ...	0	0		.105		.15		.105		0	.105		.15		.105		0	0		.105		.15		.105	0	0
− .01 sin 4 θ ...	0	0		.009		.009	0	0	.009		.009		0	0		.009		.009	0	0	.009		.009		0	0
Totals	0	0	.013	.364	.025	.599	.035	.605	.053	.440	.162	.250	.200	0	.403	.009	.484	.009	.535	.105	.474	.150	.272	.105	0	0
Sums	0	0		.351		.574		.570		.387		.088	.200		.394		.475		.430		.324		.167		0	0
$\frac{M\omega^2 r^2}{g} = \frac{57000}{17800}$				1.12″		1.84″		1.82″		1.24″		.28″	.64		1.26″		1.52′		1.38″		1.04″		.56″			
$\frac{M\omega^2 r^2}{g} = \frac{81000}{17800}$				1.59″		2.62″		2.60″		1.76″		.40″	.91		1.79″		2.16″		1.96″		1.48″		.76″			
− .0025 sin θ ...				.0007		.0013		.0018		.0022		.0024		.0025		.0024		.0022		.0018		.0013		.0007		
− .296 sin 2 θ ..				.148		.258		.296		.258		.148			.148		.258		.296		.258		.148			
− .0975 sin 3 θ..				.069		.098		.069			.069		.098		.069					.069		.098		.069			
− .0047 sin 4 θ..				.0041		.0041			.0041		.0041					.0041		.0041				.0041		.0041			
Totals				.2218		.3614		.3668	.0041	.2602	.0731	.1504	.098	.0025	.217	.0065	.258	.0063	.296	.0708	.2621	.0998	.1521	.0697		
Sums				.2218		.3614		.3668		.2561		.0773	.0955		.2105		.2517		.2252		.1628		.0824			
$\frac{R\omega^2 r^2}{g} = \frac{52600}{17800}$				.66″		1.07″		1.08″		.77″		.23″	.28″		.62″		.74′		.67″		.48″		.24″			
$M + R$ High...				1.78″		2.91″		2.90″		2.01″		0.51″	c.92″		1.88″		2.26″		2 05″		1.52″		.80″			
$M + R$ Low ...				2.25″		3.69″		3.68″		2.53″		0.63″	1.19″		2.41		2.90″		2.63″		1.76″		1.00″			
Crank angles ..	0		15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	380	345	360
$M + R$ High ..	0		1.78	2.91	2.90	2.01	0.51	c.92	1.88	2.26	2.05	1 52	.80	0	.80	1.52	2.05	2.26	1.88	0.92	c.51	2.01	2.90	2.91	1.78	0
$M + R$ Low....	1.19		0.63	2 53	3.68	3.69	2.25	0	2.25	3.69	3.68	2.53	c.63	1.19	2.41	2.90	2.63	1.96	1.00	0	1.00	1.96	2.63	2.90	2.41	1.19
Gravity.....	0.78		0.60	0.39	0.14	c.12	0.37	0.67	c.79	0.92	1.05	0.99	0.91	0.78	c.59	0.35	c.12	0.15	0.39	0.67	0.78	0.90	1.03	c.96	0.90	0.78
Resultant inertia.	1.97		1.75	c.77	c.64	1.80	2.11	1.59	0.42	0.51	0.58	0.02	1.08	1.97	2.20	1.73	0.70	0.45	1.27	1.59	1.27	0.85	0.76	0 95	1.52	1.97

SHEET No. 3.

VERTICAL CROSS-COMPOUND ENGINE.

29-60-56.

CURVE No. 1.

Horizontal scale, 1" = 60 ÷ (98.6 × 48) = 0.0127 secs.

" " 1" = (4.66 × π) ÷ 48 = 0.3055 ft.

Turning moment at crank shaft center:

Vertical scale, 1" = 17,800 lbs.

Tangential force at crank pin:

Vertical scale, 1" = 17,800 ÷ 2.33 = 7,640 lbs.

Acceleration at crank pin:

Vertical scale, 1" = (7,640 × 32.2) ÷ 1,295,000 = 0.1888 ft. per sec.

Acceleration at fly-wheel rim:

Vertical scale, 1" = (0.1888 × 108) ÷ 28 = 0.728 ft. per sec.

Areas, 1 sq. in. = 7,640 × 0.3055 = 2,335 ft. lbs.

CURVE No. 2.

Horizontal scale, 1" = 0.0127 secs.

Vertical scale, 1" = 0.728 × 6 × 0.0127 = 0.055 ft. per sec. at wheel rim.

Maximum ordinate, 5.8 ins.

Total velocity variation, 5.8 × 0.055 = 0.3215 ft. per sec.

Percentage of total velocity variation, 0.00346.

Coefficient of unsteadiness, 289.

CURVE No. 3.

Horizontal scale, 1" = 0.0127 secs.

Vertical scale, 1" = 0.055 × 6 × 0.0127 = 0.00438 ft. at wheel rim.

Maximum ordinate, 5.0 ins.

Total space variation, 5.0 × 0.00438 = 0.0219 ft.

= 0.263 ins.

= 0.1394 degs

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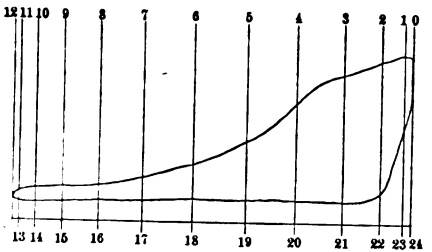
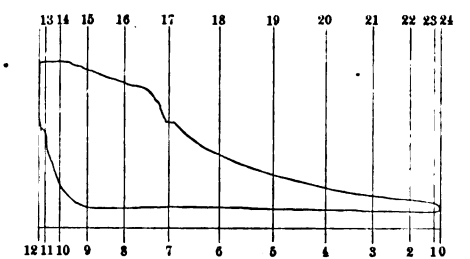
STEAM BY GAUGE	137.5 LBS.
VACUUM	24.5 INS.
SPEED	98.6 R.P.M.
AMPERES	2300.
VOLTS	526.

0	1	2	3	4	5	6	7	8	9	10	11	12	
24	23	22	21	20	19	18	17	16	15	14	13		
5¼	7	8	9	9¼	10	10	10¼	10¼	10¼	9¼	6	4	L.P.C.
-5¼	-4¼	-3¼	-2¼	-1	2	7¼	9¼	11	12¼	13	12¼	5	" " "
4¼	10¼	10¼	10	9	6¼	1¼	-1¼	-3¼	-4¼	-5¼	-6	-6¼	L.P.H.
8	7	10	11	11	11	11	10¼	10¼	10¼	10	9¼	9	" " "
126	128	121	111	87	59	43	32	26	25	23	21	17	H.P.H.
102	75	21	16	15¼	16	15	14	13	13	13	14	17	" " "
15	13	12	13	13	13¼	14	14¼	14¼	14	31	71	93	H.P.C.
15	18	21	24	30	39	55	78	108	118	123¼	123	123	" " "



80 LB. SPRING

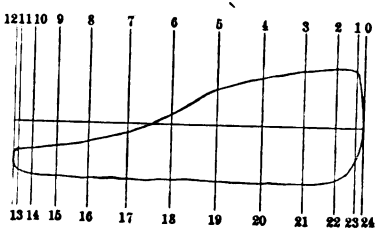


HEAD END

CRANK END

No.1 Engine – Mar.11, 1901

Series No.9



20 LB. SPRING

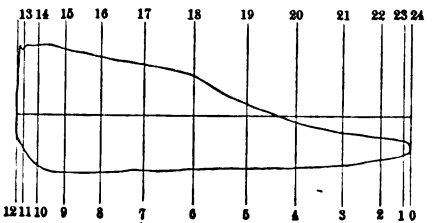


Table XI.

Table XI.

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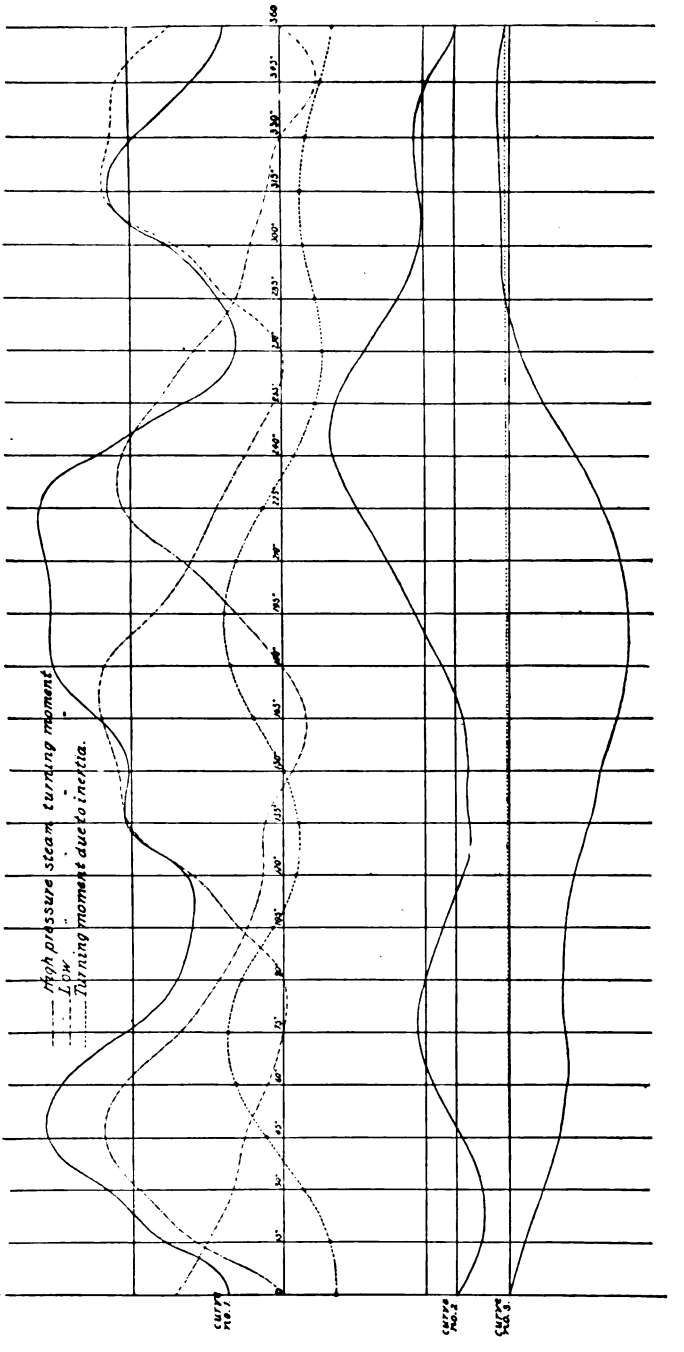

Sheet No. 3.

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A paper read at the 157th Meeting of the American Institute of Electrical Engineers, New York, October 25th, 1901, President Steinmetz in the Chair.

SPEED REGULATION OF PRIME MOVERS AND PARALLEL OPERATION OF ALTERNATORS.

BY CHARLES P. STEINMETZ.

Regarding the effect of speed regulation of prime movers on the parallel operation of alternators therefrom, three features have to be considered.

1. The permanent variation of speed, due to a change of load.

2. The temporary change of speed, due to a sudden change of load.

3. The periodic change of speed during each revolution.

1. With a change of load on the alternator, the power supplied to the prime mover must be changed correspondingly. This is done by a regulating mechanism, which is is based either on the speed (speed governor) or the acceleration (inertia governor). The speed of the prime mover is a function of the load, usually decreasing more or less with the increase of load. Since, however, alternators in parallel operation, and thus the prime movers driving them, must run in synchronism with each other, it follows that the division of load between alternators driven by independent prime movers depends on the division of power between the prime movers at (electrical) inequality of speed, but not upon the characteristics of the alternator, thus it cannot be changed by a change of excitation of the alternator, etc.; but only by reacting upon the governor (or by a change of belt tension with alternators belted to the same shaft). Therefore for parallel operation of alternators a certain drop in speed with increase of load is necessary, and with a governing mechanism maintaining absolutely constant speed at all loads, the division of load becomes indefinite and parallel operation ceases to be feasible.

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If the drop of speed with increase of load is not uniform, but the speed almost constant for moderate load, alternators may operate satisfactorily in parallel at load, but see-saw at light load.

2. With a sudden change of load, since time is required for the governor to act and for the flow of power to the prime mover to change to the condition corresponding to the changed load, a temporary change of speed occurs, larger than corresponds to the change of load, and to reduce this variation of speed, storage of energy by the momentum of the fly-wheel is necessary. With the steam engine the momentum of the steam, as expansive fluid, is usually negligible in its effect, and the temporary effect of speed depends mainly upon the rapidity of the action of the governor. With water power, frequently the momentum of the moving mass of water predominates as a cause of the speed fluctuation with sudden change of load, and the speed fluctuation thus depends upon the momentum of the total moving mass of water. Stand pipes, relief valves, and deflecting nozzles represent means to reduce or eliminate the effect of the momentum of the moving water column upon the regulation of speed at sudden change of load.

3. Most rotary prime movers, as water-wheel, steam turbine, etc., give a uniform supply of power, and thus uniform speed during the revolution. Others, however, as reciprocating prime movers, steam and gas engines, supply the energy by a number of impulses, and the torque, and therefore speed of the prime mover thus periodically varies during the revolution. The resultant torque of these prime movers consists of the pulsating torque of the energy supply (indicator diagram), the alternating torque of acceleration and retardation of the reciprocating masses, the alternating torque due to the finite length of the connecting rod, with vertical engines, the alternating torque of gravity in the ascent and descent of the reciprocating masses, and in gas engines also the pulsating negative torque of the compressor. The speed variation resulting herefrom can be reduced by such a design of the prime mover, that the different components of torque superimpose upon each other to a more nearly uniform torque, or by the use of a heavy fly-wheel. The most objectionable result of this periodic variation of speed is, however, the hunting of alternators and synchronous apparatus (as motors and converters), and this tendency to hunting seems to be aggravated by the use of heavy fly-wheels on the prime mover.

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Electrical motors as a rule are not considered as prime movers, although no reason appears for making a distinction between the supply of power through a hydraulic pipe-line or through an electric transmission line. With electric motors the rate of rotation is uniform and the periodic variation of speed thus absent, and due to the practical absence of a time lag, the temporary variation of speed at a sudden change of load absent also, constancy of the supply voltage assumed. With continuous current shunt motors a cumulative series field may be necessary for parallel operations of alternators to secure the necessary drop of speed with increase of load. With induction motors, while the drop of speed under load may be considerably less than required for good parallel operation of engine-driven alternators, the speed variation with the load is so uniform that no difficulties are met.

In parallel operation of alternators driven by synchronous motors due to the absolute constancy of speed under load, an entirely different set of phenomena occurs, similar in some respects to the parallel operation of rigidly connected alternators, but differing therefrom, due to the flexibility of the synchronous motors in their relative phases, but rigidity in frequency.

Difficulties with parallel operation of alternators driven from separate prime movers may be due to :

1. *Lack of synchronizing power*, due to excessive armature reaction. This is practically unknown with modern alternators, in which the synchronizing power is always far in excess of the requirements of keeping them in step.

2. *Surging or hunting* between the alternators. Regarding this, forced surging and cumulative or resonating surging may be distinguished. With prime movors giving a periodic variation of speed during the revolution, periodically varying cross currents flow between the alternators and between alternators and synchronous motors, in extreme cases even between alternator and induction motor, of an amplitude depending upon the amplitude of the speed variation. Under certain conditions this surging becomes cumulative, gradually increasing in amplitude so that the machines may break out of synchronism. The cause of this cumulative effect may be found in the electrical circuit in certain relations between the momentum of the moving mass and the electric constants of the circuit, or it can be found in the mechanical construction of the prime movers, fore-

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most their governors. When due to the former cause it can occur also with turbine-driven prime movers and synchronous motors ; while the mechanical hunting of the governing device which is the more frequent and serious phenomenon, is most frequently found in direct-connected, engine-driven plants.

The cumulative hunting is overcome by eliminating its cause; that is, breaking the resonance condition of the electric circuit by interference, or by changing its constants and damping the governor so as to stop its ability to hunt, or by reducing the amplitude of the hunting by a damping device in the electric circuit, usually in the field of alternators or other synchronous apparatus.

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A paper read at the 157th Meeting of the American Institute of Electrical Engineers, New York, October 25th, 1901, President Steinmetz in the Chair.

PARALLEL OPERATION OF ENGINE-DRIVEN ALTERNATORS.

BY W. L. R. EMMET.

There has been and is much diversity of opinion and practice among engineers in relation to the operating of alternators in parallel from steam engines. This paper explains a method of overcoming the difficulties of such operation which has been in successful use for three years in many important installations.

The problem to which it relates is one of the greatest importance, and the solution described is, or is believed to be, complete and universal. It is, for every reason, desirable to the whole fraternity of electrical engineers, that differences of opinion and of method in such a matter be removed or reconciled. I hope, therefore, that this paper, with the discussions which may follow it, will serve either to establish generally the use of the methods proposed, or to bring about the general acceptance of other or improved means for accomplishing the same result.

The problem of operating engine-driven alternators in parallel arose in Europe before it attracted attention in this country. Our early alternating experience was, for well understood reasons, confined to small generators operated on separate circuits. The use of direct-coupled engine-driven alternators did not begin in this country until about 1893, and the cases of parallel operation were quite infrequent until three or four years later. During the years of '95, '96 and '97, I was concerned in the installation of a number of machines of this type which were operated in parallel, but, for various reasons, none of the troubles characteristic to the parallel operation of alternators occurred in these

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cases, so that up to the year 1898 I had not encountered the problem here discussed and had done nothing towards its solution. In Europe the problem had arisen much earlier, and serious troubles had been encountered which were described in the different electrical journals. These accounts of trouble, combined with our knowledge of phenomena of hunting in synchronous apparatus, led me to be apprehensive about the parallel operation of alternators under certain conditions, before the difficulty was actually encountered.

The first case of trouble which I encountered was in the fall of 1898, when two 800 k. w. 60-cycle alternators operated at 100 r. p. m. from McIntosh and Seymour engines were put into operation in Cleveland. These machines, when thrown into parallel, immediately began to surge so violently as to render service impossible. About the same time we started two 1000 k. w. 60-cycle machines of the same type in Philadelphia and four 1500 k. w. 60-cycle machines at 120 r. p. m. in Boston. In both cases the same trouble appeared that had occurred in Cleveland, except that it was worse in both the latter cases, particularly in the case of Boston, where parallel operation was at first impossible under any condition of load.

I happened to be responsible for the engineering of these three plants, and found myself confronted with a very serious problem. I carefully considered the available European information which bore upon the subject, and found that two remedies for this trouble had been there applied. One of these remedies was described in an article by Mr. Gisbert Kapp which came to my atttention. This article explained that the period of oscillation in relative motion of parallel alternators was govered by two quantities; namely, the electrical synchronizing force, and the weights of the moving systems. Mr. Kapp explained that these quantities could be estimated and compared, and an arrangement could be adopted by which the natural period of oscillation between machines would not conform to the strokes of engine, or would be of such a frequency that trouble was unlikely to result. The other method of cure I found described by M. LeBlanc, who advocated the use of deadeners in the form of windings or attachments to the field structure in which currents would be generated by the shiftings of flux, and which would so serve to consume energy and interpose an electrical friction which must tend to kill the oscillations.

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A careful consideration of both these remedies indicated to my mind that neither of them afforded an adequate solution of the difficulty with which we were confronted Special design of dynamos to obtain certain synchronizing effects with certain loads was almost out of the question, since commercial dynamos should be adapted to operation under all conditions, so that the investment in them may not be lost when change of condition is brought about through growth or other circumstance. M. LeBlanc's method was also objectionable, since it introduced devices which must occupy valuable space, and complicate the design of machines, and which must, under operating conditions introduce more or less serious losses. It was furthermore reasoned that a simple deadener could not be complete in its effectiveness since the deadening effect must increase in proportion to the oscillation, and must be very small where the angle of oscillation is slight. It therefore seemed that this disappearing quantity would probably limit the extent of oscillations, but could hardly be expected to entirely prevent them under all conditions. Our subsequent experience showed that both of these methods were sound in theory and practicable within certain limits, but also developed the fact that they could not be depended upon as a basis of commercial work under various conditions.

At the same time that these theories were being considered I started a set of investigations with a view to ascertaining the exact conditions which existed in engine and dynamo while these troubles were occurring. In conducting these investigations, I reasoned that there must be a powerful actuating force employed in keeping these oscillations alive, since the waste of energy incident to their maintenance must necessarily be large, even where no pole-piece attachments or other form of deadeners are used. Theory clearly indicated that the oscillation was a pendulum action, whose period was governed by the weight and by the synchronizing power. I reasoned that this pendulum continued to swing in spite of a heavy friction, and I conducted my investigation with a view to ascertaining the actuating force. I presumed that this actuating force must come from the steam in the engine cylinders, and I had careful sets of indicator cards made showing the impulses under successive strokes and in the different cylinders. The comparison of these indicator cards immediately showed that there was a large irregularity in the delivery of steam to engines, and that the differences ef area in

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different cards or in cards which should be the same under fixed load were very great. It was further observed that these variations arose from periodic motions of the governor, and that they conformed in period with the swing of the machines, and with the fluctuations of electro-motive force and current.

These facts, which were communicated to me by letter from Cleveland, led me to believe that the cure for the trouble must be sought in a prevention of a rapid periodic motion in the engine governors. I explained this in letters to the engine builders, suggesting to them that retarding dash-pots be used on their governors, which would prevent these sudden motions. The builders of the Cleveland engines, in return, replied that their governors were fitted with dash-pots, and that they were of the best anti-hunting type then known to the art. By such correspondence I soon discovered that the matter was entirely beyond the practical experience of the engine builders, and that we could hardly expect them to afford us a solution of the problem. I then went myself to Philadelphia, where the conditions for experiment were favorable, first communicating my theory in writing to the purchaser and to the engine builder as a matter of record. The governors of engines in Philadelphia were so arranged that dash-pots could be very readily attached to them, which would limit the speed of their motion to any desired degree. Our first experiment was to block the governors positively and run with fixed load. Under this condition, no sign of oscillation appeared. We then operated the engines under various conditions of load and excitation, with and without dash-pots having various degrees of stiffness. These investigations showed that the tendency to oscillation gradually disappeared as the freedom of the governor was limited by the dash-pot. Under certain conditions a small dash-pot effect would kill the oscillation altogether, while under other conditions a stiffer dash-pot would be found necessary. In every case, however, the dash-pot effected improvement, and the cure seemed to be simply a matter of degree. In this particular case, it was found that satisfactory parallel operation under all conditions of service could be obtained with dash-pots which were not so stiff as to materially interfere with the quick action of the engines, and such a cure was adopted, so that the investigations were not carried further in this plant.

From my experience in Philadelphia, however, I reasoned that other cases would arise where such a cure could not be applied,

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since the dash-pots necessary to afford stability of parallel operation would be too stiff to admit of the proper quick governing of the engines. These anticipations were very soon realized in the operation of the machines above mentioned at Boston. In these machines the oscillating tendency was so strong that they could not keep in step at half load with dash-pots so stiff as to admit dangerous variations of speed with sudden load fluctuations From this experience it was seen that we must find some means of deadening the motions of the governor occasioned by the oscillations, and at the same time we must leave the governor free to move where actual changes of load came upon the machine. A means of accomplishing this result was devised in Cleveland by the combined efforts of Mr. H. W. Buck, my assistant, and Mr. Harte Cook of the McIntosh and Seymour Co. The device is shown in Fig. 1, which shows only one of many forms devised for accomplishing practically the same result. The main piston rod shown in this sketch is connected to the governor weights in such a manner as to be moved directly by them. The space on both sides of the piston and all the port spaces are filled with a heavy grease. By-passes, F, are provided, through which this grease can flow from one side of the piston to the other. Each of these by-passes is actuated by a small piston-valve, C, backed by a spring, G, and provided with a small by-pass, B. The practical effect of this device is that the springs tend always to keep the gates of the main by-passes closed, and that the piston is thus virtually locked until the pressure at one end of it has forced the by-pass valve back. The first motion of the main piston is thus limited by the size of the small by-pass, B, whereas its later motion, after the valve has been forced back, is limited only by the size of the main by-pass, F. It will be readily seen that this dash-pot can be so adjusted that it will act as a temporary lock on the governor mechanism, and that it will release entirely after the tendency to govern has continued for a certain length of time.

Such dash-pots were first applied to the engines above mentioned operated in the plant of the Boston Electric Light Co., and it was found that they afforded a positive and complete cure of the oscillating troubles which had been experienced there. By their use, with proper adjustment, the engines can be operated under all conditions of load, and with any number in parallel, without the slightest indication of the oscillating trouble which

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was at first so difficult to prevent. In this case the tendency to oscillation was much more positive than in any other which has come to my notice, and the perfect success of the remedy has led me to believe that the method is universally applicable, and that all similar troubles can be cured by its intelligent application.

In order that this form of dash-pot may properly accomplish its functions in the most difficult cases, it must be made strong enough mechanically and hydrostatically to bear, for a time, the entire force imposed by the governor weights in their effort to assume a new position, and the period of such opposition must be such that the dash-pot will not unlock within the time of a single period of oscillation when the machines are operating in parallel. It is also necessary that the dash-pot be kept full of grease, so that there will be no lost motion through air spaces. If the dash-pot falls short in any of these particulars, the remedy which it affords will only be partial, and in difficult cases it may prove inadequate. It is only in certain difficult cases that we need use such complete preventives as were found necessary in Boston.

While discussing this subject, it may be profitable to briefly touch upon a few other facts which have developed in the course of my experience in the parallel operation of alternators. It is popularly supposed that it is necessary to use very heavy fly-wheels in order that alternators may be successfully operated in parallel; it being the custom of some engineers to consider a guarantee of small angular variation as the equivalent to a guarantee for parallel operation. My experience has rather indicated that generators with light fly-wheels are most easy to operate in parallel. The frequency of natural oscillations in such machines is high, and the conditions of engine operation are generally unfavorable to their development. Large fly-wheels are desirable on direct coupled alternators, because a steady frequency is a valuable feature in any system. The requirements of parallel operation, however, are rather unfavorable than otherwise to the use of heavy fly-wheels.

The peculiar periodic action of an engine's governor which I have before described, is not confined entirely to the parallel operation of alternators, but also may occur and cause trouble where a single alternator is operating a load of synchronous apparatus. We may even have alternators which will operate together in parallel, but which will, through periodic action of the governors, give trouble with certain loads of synchronous

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apparatus. It is thus desirable in all cases to prevent this periodic action of the governors, and by this prevention many troublesome difficulties may be lessened or overcome.

The behavior of all parts of the system while this oscillating trouble occurred in parallel operation was very beautifully illustrated during our experiments in Philadelphia. The shafts of engines were in line, and the relative positions of poles could, at all times, be seen, the poles of one machine appearing to stand still when the machines were in perfect synchronism. The movements of the governor mechanism could also be seen by oscillations of a lever arm which was in the line of vision. Ammeters and voltmeters were also placed in the same line. It was possible at a glance to see the degree of angular displacement of the poles, the degree of motion of the governor, and the fluctuations of the current and voltage. An observation of these conditions showed very clearly the exact character of this phenomenon. It was found that under some conditions the oscillation was an extremely sensitive matter, and had very little power of sustaining itself. A slight change in the field strength of one of the machines would sometimes break it up so that it entirely disappeared, after which the machines might remain steady for some time and then gradually begin to swing again. Under other conditions it was more persistent. Everything indicated, however, that it could not exist for any appreciable period without the actuating force afforded by the irregularity of steam impulses.

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A paper presented at the 157th Meeting of the American Institute of Electrical Engineers, New York, October 25th, 1901. President Steinmetz in the Chair.

PARALLEL RUNNING OF ALTERNATORS.

BY ERNEST J. BERG.

In the following article an endeavor will be made to show the principles govering parallel operation of alternators, driven by steam engines or turbines. The laws of parallel running when generators are driven by electric motors depend so much upon the action of the motors that this part of the subject is omitted and reserved for another paper.

Consider two alternators intended for parallel operation, and let:

e = induced E. M. F.

$Z_1 = r_1 - j\, x_1$

$Z_2 = r_2 - j\, x_2$ = the internal impedance of the different armatures.

Y_1 and Y_2 = the corresponding admittances.

$Z = r - j\, x$ = the impedance of the external load.

Y_3 = joint admittance of the armature circuits.

Z_3 = corresponding impedance.

Z_0 = total impedance in the circuit.

We have then:

$$\left.\begin{aligned} Y_1 &= \frac{r_1}{Z_1^2} + j\,\frac{x_1}{Z_1^2} \\ Y_2 &= \frac{Y_2}{Z_2^2} + j\,\frac{x_2}{Z_2^2} \end{aligned}\right\} \quad Y_3 = Y_1 + Y_2$$

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$$Z_3 = \frac{1}{Y_3}$$

$$Z_0 = Z_3 + Z$$

$$\text{Total current } I = \frac{e}{Z_3 + Z}$$

$$\text{Voltage across load} = I\,Z = \frac{e\,Z}{Z_3 + Z}$$

$$\text{Drop in armatures} = e - \frac{e\,Z}{Z_3 + Z}$$

$$\text{Current in armature No. 1} = \left(e - \frac{e\,Z}{Z_3 + Z}\right) Y_1$$

$$\text{Current in armature No. 2} = \left(e - \frac{e\,Z}{Z_3 + Z}\right) Y_2$$

$$\text{Volt-amperes of one armature} = e^2\,Y_1\left(1 - \frac{Z}{Z_3 + Z}\right)$$

$$\text{Volt-amperes of one armature} = e^2\,Y_2\left(1 - \frac{Z}{Z_3 + Z}\right)$$

Power of each armature is the real part of the expression for volt-amperes.

This is expressed as:

$$P_1 = e^2\,\frac{(p\,r_1 - q\,x_1)}{(m^2 + n^2)\,(r_1^2 + x_1^2)}$$

and

$$P_2 = e^2\,\frac{(p\,r_2 - q\,x_2)}{(m^2 + n^2)\,(r_2^2 + x_2^2)}$$

where:

$$p = m^2 + n^2 - m\,r - n\,x$$

$$q = m\,x - n\,r$$

$$m = \frac{G}{G^2 + B^2} + r$$

$$n = \frac{B}{G^2 + B^2} + x$$

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$$G = g_1 + g_2$$
$$B = b_1 + b_2$$
$$Y_1 = g_1 + j\, b_1$$
$$Y_2 = g_2 + j\, b_2$$

Neglecting the resistances of the armatures as compared with the reactances, we get the following expressions:

$$P_1 = \frac{e^2\, x_2\, r\, (x_1 + x_2)}{Z^2\, (x_1 + x_2)^2 + x_1^2\, x_2^2 + 2\, x\, x_1\, x_2\, (x_1 + x_2)}$$

$$P_2 = \frac{e^2\, x_1\, r\, (x_1 + x_2)}{Z^2\, (x_1 + x_2)^2 + x_1^2\, x_2^2 + 2\, x\, x_1\, x_2\, (x_1 + x_2)}$$

In other words, the alternators divide the load inversely as their armature reaction.

With a non-inductive external circuit, these questions become:

$$P_1 = \text{power of one armature} = \frac{e^2\, r\, x_2\, (x_1 + x_2)}{r^2\, (x_1 + x_2)^2 + x^2_1\, x_2^2}$$

$$P_2 = \text{power of other armature} = \frac{e^2\, r\, x_1\, (x_1 + x_2)}{r^2\, (x_1 + x_2)^2 + x_1^2\, x_2^2}$$

which with close approximation can be written:

$$P_1 = \frac{e^2\, x_2}{r\, (x_1 + x_2)}$$

$$P_2 = \frac{e^2\, x_1}{r\, (x_1 + x_2)}$$

Therefore two machines of same induced E. M. F. and armature reaction running in phase will share the load evenly. If one has twice as high armature reaction as the other, it will take one half of the load, etc. Thus since machines of identical regulation have practically armature reactions inversely proportional to their size, it is possible to run such machines from the same engines at proper share of the total load. Should, however, two machines of the same size and different armature reaction run from the same engine, the distribution of power will not be in accordance with the rating.

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To balance the load it is then necessary to add reactance in one armature or to mechanically offset one armature in regard to the other, or, finally, to run them at such field excitation as will cause considerable cross-current, which effect will be discussed later.

In the discussion given above it was assumed that the machines were running strictly in phase, which would practically limit the case to alternators clutched together. If, however, they are rigidly connected together, but out of phase, the current which is due to the resultant of the two E. M. F.'s has a different phase displacement from the E. M. F. of one machine than it has from that of the other, that is, the energy corresponding is different in the two machines, or the one supplies more power than the other.

The relation of currents to E. M. F.'s can also be changed by changing the excitation.

Assume machines of the same armature reaction which, before being thrown in parallel, have unequal E. M. F.'s. After being connected together their terminal voltages must be the same, therefore a cross-current must flow between them which, in the higher excited alternator, is lagging, and in the other leading; which currents, in conjunction with the field excitation, give a resultant field of same magnitude in the two, but displaced in phase. In the higher excited machine it will bring the resultant field more in phase with the energy current, thus giving a result equivalent to an armature of lower reactance; in the lower excited machine a result same as higher armature reaction. It is therefore possible to change the load by change of field excitation by sacrifice of current, since this method involves wattless currents between the generators.

In view of the above discussion, it is thus evident that the question of distribution of power between alternators is quite simple, if they are running at absolutely the same speed at all loads; that is, if the engines regulate so closely as to permit the clutch to be opened and the armatures still retain the same positions. In reality, however, engines cannot be made to govern so closely, but one will tend to hold up the speed somewhat better than the other. That being the case, it is safe to say that as a rule the engines will not tend to give the same power at exactly the same speed.

Referring back to the equations and discussions we find, there-

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fore, that with the same armature reaction and induced E. M. F., if different power is given each machine, the armatures must be offset a certain and fixed degree, which means that by even the most minute difference in speed regulation the armatures are forced to change their relative positions, which obviously is a cause for "hunting."

The relative power given by each machine depends upon the respective powers of the engines at identical speeds.

From the above discussion it is apparent that a definite tendency for "hunting" exists, and that this hunting is manifest in a mechanical pulsation in the speed of the armatures, and a transfer of power from one unit to another.

A most superficial investigation will show that this flow of power is much greater than that corresponding to the stored energy of the armature fly-wheel, etc., at the relatively small differences in speed, and that pulsating power actually has to be supplied by the engines. Therefore, and since power cannot be obtained from an engine without corresponding steam, the flow of steam must be periodic to sustain an accumulated hunting.

The remedy is therefore to be found by preventing such periodic flow of steam, which can be accomplished by proper dash-pot arrangements at the governor. Other remedies also suggest themselves, the favorite being to make a short-circuited winding in and around the field of alternators. The object of such winding obviously is to establish a load when these oscillations occur, which load tends to stop the acceleration and retardation of the armature. The disadvantages of this method are that losses of no small magnitude not only are introduced when the machines hunt, but also when they are running at steady speed, which losses are caused by induced currents in this short-circuited winding, due to pulsations of flux incidental to modern construction of iron-clad armatures.

Schenectady, October 14th, 1901.

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ANGULAR VELOCITY IN STEAM ENGINES IN RELATION TO PARALLELING OF ALTERNATORS.

BY WALTER I. SLICHTER.

Certain characteristics of the steam engine which are of no importance in most applications of power other than electrical and even in electrical when D. C. generators are used, become of considerable importance when the engine is direct connected to an alternating current generator. These are the peculiar variations in tangential effort on the crank, and the consequent variation in speed of the shaft and fly-wheel.

The angular velocity of the fly-wheel varies in two entirely different ways, due to two different causes. The first and best known is that due to a change of load, then the average velocity changes, and there is a change in the number of revolutions per minute.

The second effect is due to irregularities in the applied force and transmission of that force, and consists in a variation of the instantaneous value of the angular velocity, while the average value and the revolutions per minute remain the same and constant.

The first is altogether a function of the governor of the engine. The latter phenomenon, which is the one to be discussed in this article, is more complicated both in its causes and effects, as it introduces the distribution of the steam pressure in the cylinder, inertia of reciprocating parts, angularity of connecting rod and moment of fly-wheel. It is of importance where two or more alternators are to be run in parallel, or where synchronous motors

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are to be run from one or more alternators. Such machines tend to run in exact synchronism, and their inertia gives them a tendency to run at constant angular velocity. If now an irregular pulsation is impressed upon the system by the steam engine, there is a continual effort in each machine to keep in exact step with this pulsation, which causes an exchange of cross-currents and a liability of falling out of step.

When two alternators are running in parallel, if they differ in angular position, even if revolving at the same speed, a cross-current will flow between them, tending to pull them together. This cross-current may be wattless but even then it consumes some energy in the form of $I^2 r$.

Assuming that we wish to limit this cross-current to 10% of the full load current of one generator, what angular displacement will be allowable?

Taking several representative alternators having an average regulation of 9%, we find the average short-circuit current is 2.5 times full load current, thus the synchronous impedance is

$$z = e/i = E/2.5.$$

The difference between any two sine waves having an amplitude E and displaced in phase by an angle β is $2\ E \sin \beta/2$. This E. M. F. is short-circuited through the impedance of the two alternators in series.

$$\text{Thus cross-current} = e/z = \frac{2\ E \sin \beta/2}{2 \times E/2.5} = 2.5 \sin \beta/2$$

placing this equal to .10, we have $\sin \beta/2 = .04$, $\beta/2 = 2.3°$ displacement between one wave and mean.

If we say 2.5° displacement for round numbers, we have a cross-current of .109.

(A displacement of 2.5° in the electrical circuit is caused by a much less displacement of the fly-wheel. There is one complete cycle of E. M. F. generated per pair of poles. Thus if p is the number of pairs of poles on the generator, there are $p \times 360$ degrees of E. M. F. generated in one revolution of the fly-wheel. That is, one degree on the fly-wheel equals p degrees of E. M. F.)

The causes of the irregular effort are: The pressure of the steam on the piston due to cut-off and expansion is uneven, being great during the first part of stroke, and small and even negative, due to compression, at the end. In the vertical engine the weight of the piston, rod, cross-head and part of connecting rod have to be lifted on the up-stroke, but are additive to the steam pressure on the down stroke. This makes a difference in

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the power of each stroke, raises the peak of one and increases unbalanced energy.

This pressure is transferred to the crank-pin through a varying angle so the effort is roughly equal to $P \sin \varphi$, varying between zero at beginning and end of stroke and P at middle. Thus there is a combination of maximum values at the point of cut-off, as that comes near the middle of the stroke, and we get quite a pointed peak here.

The angularity of the connecting rod has a different effect in the forward and backward strokes, as in the forward stroke during the early part while the pressure is high anyway, it increases the effect of that pressure on the crank pin, and in the latter part it diminishes that effect. On the return stroke it has the reverse effect, diminishing in the early part and increasing in the latter. So that the final effect is to increase the peak of one impulse and diminish the peak of the other.

The inertia of reciprocating parts absorbs energy at the beginning of the stroke, and gives it up at the end, so it has a beneficial effect on the diagram, smoothing the peak and raising the low values. The combination of two or more cylinders on the shaft naturally tends to even the effort and also to diminish the length of time one impulse lasts, thus diminishing its effect.

Combining the effort of three cylinders would seem to give a more even torque than two cylinders, but the actual diagrammatic combination shows there is very little choice between a two cylinder or three-cylinder engine.

In a single cylinder, double-acting engine there are two impulses per revolution, and in a cross-compound engine there are four impulses. Each impulse is more or less like any other. By analyzing the variation in speed during one impulse we can derive our conclusions. Though as all the impulses are not equal, it is as well to select that impulse having the greatest amount of unbalanced energy so as to know the worst conditions.

During the first quarter of impulse, the effort is less than average, during the second and third quarter (approximately) the effort is greater, and during the last quarter it is low again. The unbalanced effort represents a force which, acting on the mass of the fly-wheel, produces an acceleration, $a = f/m$. Thus by referring the torque diagram (Fig. 1.) to the line of average torque as base, we get a curve of acceleration.

Integrating this acceleration, we get a curve of velocity v.

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This curve lags 90° behind the acceleration curve. Thus starting from a point of minimum torque a, the acceleration will be negative. From a to b the torque is less than average, the acceleration negative, the speed will keep dropping in value until b is reached, where, since the acceleration changes sign, v is a minimum, and commences to increase again; v will keep on increasing as long as the acceleration is positive, or to d, where v has its maximum value.

If we assume the variation is sinusoidal, then the average value of v from a to c is v_1, and of s, the percentage variation in speed, is $2\,s/\pi$.

The speed is low from a to c, or while the crank is passing $\theta°$ of the crank circle; during this time the crank continually falls behind the position it would maintain at constant angular veloc-

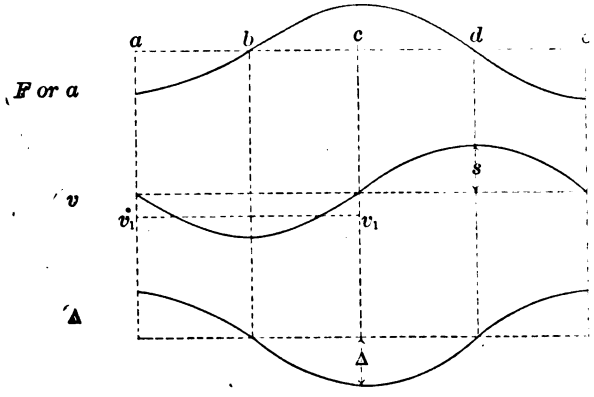

FIG. 1.

ity, and at c the maximum displacement occurs, for there the speed again becomes greater than average.

If the maximum displacement from mean is Δ, then during this time the change is from $+\Delta$ to $-\Delta$ or 2Δ for an average change in speed of $2\,s/\pi$.

That is, if speed is an average of $2\,s/\pi$ low during this time, the number of degrees passed will be $\theta\,(1 - 2\,s/\pi)$ and the change will be $2\Delta = \theta \times 2\,s/\pi$ or $\Delta = s\,\theta/\pi$, where $\theta = 360/2\,n$ approximately.

a the electrical displacement will be:

$$a = \frac{s\,p\,\theta}{\pi} \text{ or } \frac{s\,p\,360}{2\,\pi\,n} \text{ and } s = .0174\,\frac{a\,n}{p}$$

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where p = number of pairs of poles

n = number of impulses per revolution.

It is not always safe to assume $\theta = 360/2n$, as in cross-compound engines one impulse is frequently very much suppressed (due to reciprocating parts) and another prolonged and enlarged, and the longer an unbalanced torque lasts, the greater the displacement even if the total unbalanced energy is no greater.

It is interesting to note in this formula for α that the greater P, the greater the displacement angle and the greater n, the less the displacement. Hence the advantages of low frequency and multi-crank engines.

Substituting for α the value 2.5° which we have assumed, we find the allowable speed variation to be $s = .0435\ n/p$ where s is per cent. variation from mean.

A very good approximation of the fly-wheel necessary may be obtained quickly, thus:

The change of energy stored in fly-wheel for any change in speed is:

$$P_1 = w/2g \times (v_2^2 - v_1^2).$$

If v_0 is the mean linear velocity of w and $2s = (v_2 - v_1)/v_0$, then $v_2^2 - v_1^2 = v_0^2 \times 4s$, thus:

$$P_1 = w/2g \times v_0^2 \times 4s.$$

P_1 is the unbalanced energy of one impulse in foot pounds given by area P_1 in Fig. 3 and k, the unbalancing factor, is the ratio of this excess area to the energy of one revolution given by area enclosed by line of average torque.

Hence:

$$P_1 = k \times P = k \times \frac{\text{K.-W.} \times 33{,}000}{.746 \times eff \times \text{R. P. M.}}$$

where P is the energy per revolution of crank.

K.-W. = output of generator.

eff = efficiency of generator.

Equating these two values of P_1

$$\frac{w}{2g} \times v_0^2 \times 4s = k \times \frac{\text{K.-W.} \times 33{,}000}{.746 \times eff \times \text{R. P. M.}}$$

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and putting for s its value in terms of displacement a

$$w\, v_0^2\, a\, n \times eff \times \text{R. P. M.} = k \times \text{K.-W.} \times p \times 41 \times 10^6$$

$$w\, v_0^2\, a \times eff \times \text{R. P. M.} = k \times \text{K.-W.} + p \times \theta \times 226 \times 10^3.$$

In this we have three quantities—w, weight of fly-wheel; k, unbalancing factor, and a, displacement—two of which may be varied to obtain a satisfactory value of the third.

The exact calculations are much longer and involve integrating first the torque curve (which is also an acceleration curve to another scale since $a = F/I$ to get a velocity curve and integrating this velocity curve to get the space curve.

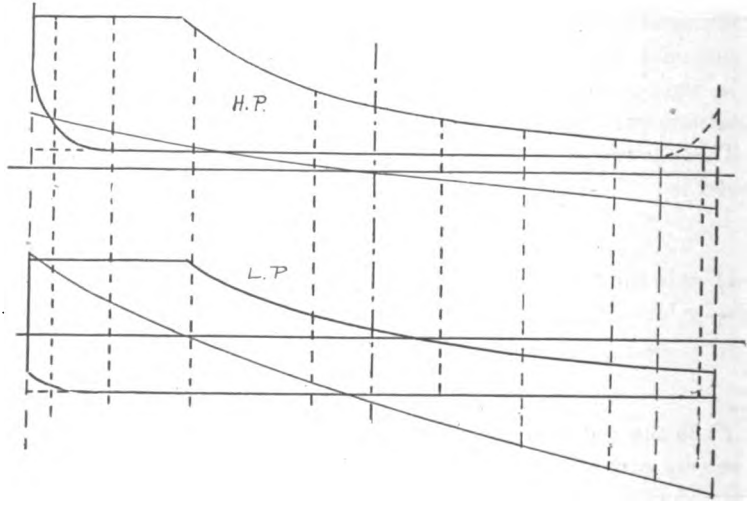

FIG. 2.

Let us take the two indicator cards shown in Fig. 2. These are the theoretical cards of a vertical cross-compound engine of 600-horse power at 150 R. P. M. to be direct connected to a three-phase 400-K. W., 48-pole, 60-cycle alternator to be run in parallel with other generators driven by water-wheels. These cards and data were submitted by one of our largest engine building companies with their proposition in answer to a request for bids.

The cylinders are 17″ and 36″ in diameter, stroke 30″, connecting rod 75″ or 5 cranks, boiler pressure 150 lbs., vacuum 26″, 145 lbs. initial pressure in cylinder, and 22% cut-off in H. P. cylinder. Both cards are reduced to L. P. piston area and the spring scale is 30 lbs. per inch.

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Weight of piston	284 H. P.	1591 L. P.
" " piston rod	173 "	173 "
" " cross-head	284 "	284 "
" " connecting rod	571 "	571 "

The fly-wheel weighs 34000 lbs. and the outside diameter is 12′, radius of gyration 4.67′.

TABLE I.

HIGH PRESSURE CYLINDER.

A Crank Angle.	B Stroke.	C Steam Pressure.	D Weight Parts.	E Inertia.	F Net Pressure.	H Sin ϕ.	I x.	K Tang. Effort.	L Moment.
....	....	28.8	+.7	—11.1	18.4	....	....	....	.....
18	.03	28.8		—10.5	19	.309	.368	7	8,900
36	.115	28.8		— 7.8	21.7	.588	.687	14.9	19,000
54	.237	26.4		— 4.8	22.3	.809	.905	20.2	25,800
72	.415	14.1		— .6	14.2	.951	1.01	14.3	18,200
90	.600	7.5		+ 1.8	10	1.00	1.00	10	12,750
108	.725	5.1		+ 3.3	9.1	.951	.89	8.1	10,300
126	.833	3.6		+ 5.1	9.4	.809	.712	6.7	8,550
144	.922	2.4		+ 6.0	9.1	.588	.49	4.5	5,750
162	.980	—4.5		+ 6.6	2.8	.308	.248	1.6	2,040
180	1.00	—12.9		+ 7.5	—4.7	...	..	....	.....
			LOW PRESSURE CYLINDER.						
90		29.5	+2.29	—32.	— .2		...	....	.....
108		29.5	2.3	—25.8	+ 6		.368	20.2	2,800
126		29.5		—18.9	12.9		.687	8.9	11,300
144		27.6		—11.7	18.2		.905	16.5	21,000
162		17.4		— 2.1	17.6		1.01	17.8	22,700
180		11.4		+ 6	19.7		1.00	19.7	25,100
198		9.6		+12	23.9		.89	21.3	27,200
216		7.5		+15.6	25.4		.712	18.1	23,100
234		6.6		+18	26.9		.49	13.2	16,800
252		3.6		+20	25.9		.248	6.4	8,200
270		....		+21.3	23.6		....	....	.....

Dividing the crank circle into a number of equal parts, say 20, each division representing 18°, we now find the position of piston when the crank passes each division; this is usually done graphi-

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cally by striking circles of a radius $= l =$ connecting rod through each point on circle; this divides the diameter in a ratio equal to per cent. of stroke.

Analytically we get this[1] as

$$s = r\,(1 - \cos\varphi) + l\,[1 - \sqrt{1 - r^2 \sin^2\varphi/l^2}]$$

where:

$s =$ stroke in feet.

$r =$ crank length in feet.

$l =$ connecting rod length in feet.

$\varphi =$ crank angle assumed.

The net pressure on piston (difference in pressure on two sides) for each value of s is taken from indicator card and tabulated in Column C, Table 1. For convenience, pressure per square inch of low pressure cylinder is used.

The total weight of reciprocating parts divided by area of piston ($A = 1020$) is given in Column D. These are added on down stroke and subtracted on up stroke. In this instance only the down stroke is considered.

The inertia of the reciprocating parts is next taken as in Column E. This[2] is found from:

$$F = \frac{w\,v^2}{g\,r}\,(1 + r/l) \text{ and } F = \frac{w\,v^2}{g\,r}\,(1 - r/l)$$

the accelerating force at the beginning and end of the stroke respectively. In this $w =$ weight of piston, piston-rod, cross-head and half the weight of connecting rod, $g = 32$, $v =$ linear velocity of crank pin, $r =$ crank radius, $l =$ length of connecting rod.

The correct curve of inertia is very complicated, but is best approximated by plotting the two values given above and the point at which the acceleration is 0 and drawing a curve. This zero point is accurately enough given by $\tan\varphi = l/r$. This is given in Column E.

The acceleration of connecting rod used above differs very slightly from the correct value which is very complex, due to its peculiar motion.

Divide F by area of piston, and we have f, the pressure per square inch on piston.

1. Perry "The Steam Engine."

2. Unwin, "Machine Design," p. 68.

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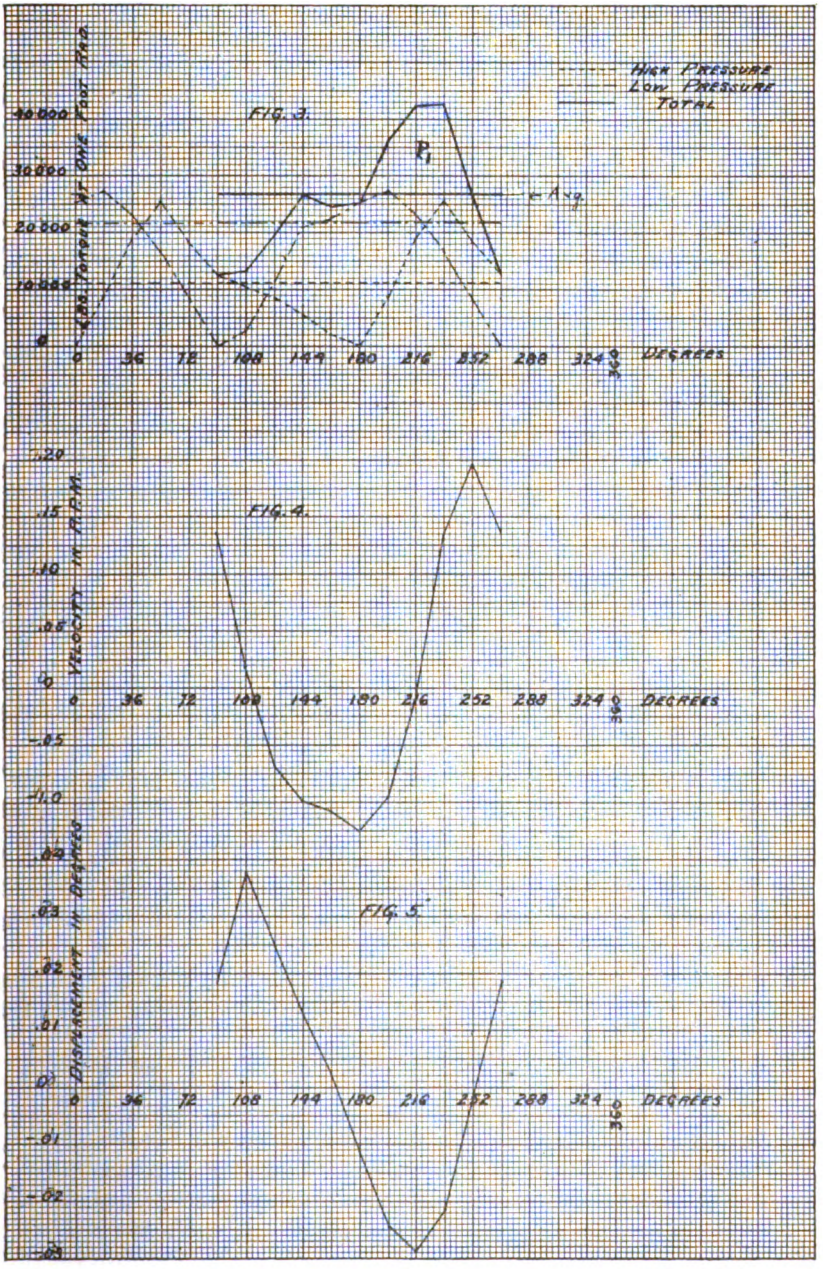

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This is negative, or absorbs energy during the first half of stroke, and positive in the second half.

On the high pressure cylinder the effect of inertia is not very noticeable, but on the low pressure cylinder, due to its larger size, the effect is quite marked. It almost completely suppresses the peak of the impulse curve. (See Fig. 3).

These values in Columns C, D and E are combined algebraically, giving net pressure per square inch of piston, in Column F.

This has to be transferred to crank pin through an angle φ and would give $P \sin \varphi$ were it not for the shortness of the connecting rod. This effect causes the resolution of forces to be more complicated, and we have[1] the tangential effort T on crank. Column K.

$$T = P \sin \varphi \left(1 + \frac{r \cos \varphi}{\sqrt{l^2 - r^2 \sin^2 \varphi}}\right)$$

For comparison the value of this with $P = 1$ and $l/r = 5$, are given along with that of $\sin \varphi$, Columns H and I.

We have now the crank effort which, by multiplying by A, area of piston, and r the crank radius, gives the actual moment $F \times r$ in foot pounds. Column L. This we must also find for the L. P. cylinder and combine in proper phase relation, usually 90° behind the high pressure. Column A, Table II.

The next step is to find the average of the resultant moment. This should be averaged for one revolution, but if we take it for a half a revolution, assuming that the energy of two halves are equal, it will be satisfactory. This assumes that the effort is the same at the beginning and end of the half revolution. Column B is unbalanced moment at each period.

Find the average unbalanced force for each period (Column C, Table II) this acting on the fly-wheel produces an acceleration.

$F = Ia$

$a = Fg/w\, r^2$

in radians per sec. per sec.

where a is acceleration.

w = weight fly-wheel,

r = radius gyration.

1 Ewing, "The Steam Engine," p. 310.

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As the speed does not vary to a great extent, we can assume without much error that equal angles are passed in equal times, therefore the time t in passing 18°, or 1/20 revolution

$$t = \frac{60 \text{ sec.}}{\text{R. P. M.} \times 20}$$

and at the end of the period the velocity will be changed $a \times t$ in radians per sec. or multiplying by $60/2\pi$ we get the change in R. P. M., Column D, Table II.

These values are the change in turns per minute for each period so at any point the actual velocity will be the progressive sums of these preceding gains $+ c$ (the velocity at the beginning of the stroke) since $\int dv = at + c$.

To find the velocity at the beginning of the stroke we sum all the values in Column E and get:

$$+ .062 - 1.1415 + 10c = 0$$

This is equal to 0, since we assumed 180° to be a complete period beginning and ending with the same point, hence all the positive values must equal all the negative values. Having found c, we add this to each value in Column E, and get the actual velocity in Column F.

We must now integrate the velocity curve to get displacement curve. This is done in the same way as we obtained velocity from acceleration, thus: Find average velocity for each period. Multiply the average velocity for each period by

$$t = \frac{1}{150 \text{ x } 20}$$

the time in minutes to pass 18°, and we get the displacement in turns, and multiply this by 360 and get the displacement in degrees of the crank circle. This is given in Column H as change of position. Summing these as we did the acceleration, we get $(\Delta + c)$, the relative position.

Eliminating c we get in Column K the final displacement from mean on crank circle.

To find the electrical displacement select the maximum value and multiply by p, the number of pairs of poles on the alternator.

$$\text{This is: } .0379 \times 24 = .91°$$

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TABLE II.

Crank Angle.	A Total Torque.	B Unbalanced Torque.	C Average Excess.	D Gain in R. P. M.	E Relative Velocity at +C.	F Velocity.	G Average Velocity.	H Change of Position Degrees.	Relative Position.	Displacement.
90	12750	−14200	−14025	.....	0	+.135	+.077	.....	0	+.0187
108	13100	−13850	−13475	−.116	−.116+C	+.019	−.025	+.0092	+.0092+C	+.0379
126	19850	− 7100	− 3650	−.087	−.203+C	−.068	−.083	−.0030	+.0062+C	+.0249
144	26750	− 200	− 1205	−.03	−.233+C	−.098	−.103	−.010	−.0038+C	+.0129
162	24740	− 2210	− 2030	−.01	−.243+C	−.108	−.116	−.0124	−.0162+C	+.0025
180	25100	− 1850	− 3650	−.017	−.260+C	−.125	−.110	−.0139	−.0301+C	−.0114
198	36100	+ 9150	+ 3650	+.03	−.230+C	−.095	−.044	−.0132	−.0433+C	−.0246
216	42100	+15150	+12150	+.101	−.129+C	+.006	+.070	−.0053	−.0486+C	−.0269
234	42600	+15650	+15400	+.128	−.001+L	+.134	+.165	+.0084	−.0402+C	−.0215
262	26400	− 550	+ 7550	+.063	+.062+C	+.197	+.166	+.0198	−.0204+C	−.0017
270	2750	−14200	− 7350	+.061		+.135		+.0199	.0005+C	+.0187

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This engine has a very small unbalancing factor and large fly-wheel, and is a very good one for the purpose. The fly-wheel could be made lighter. I might say that these particular engine builders claim to make a point of using a safety factor of 50%, at least in meeting our requirements.

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Discussion.

The President:—Gentlemen, we have listened to a series of very interesting papers. I desire to draw your attention to one point in Mr. Slichter's paper—the figure which he mentions toward the end, less than one degree displacement. This is very interesting considering that the engine has by no means an abnormally heavy fly-wheel. Very often you find steam-engine builders, if you specify two-and-a-half or three degrees displacement, claim that engines of so close regulation cannot be built without enormous fly-wheels. But here you see, apparently without great difficulty, a value reached very much below such specification. There are a number of gentlemen here who can speak on the subject. I am sorry they could not send us the manuscript beforehand, so that it could be distributed to you some days before the discussion. There is a communication from Mr. R. H. Rice which I will call upon the Secretary to read.

The Secretary read the following

Communication from Mr. R. H. Rice.

In designing engines to operate alternating current generators in parallel, two features of the design must be carefully worked out. These are:

I. The fly-wheel.

II. The governor.

I. In determining the proper fly-wheel effect for any given case it is necessary to know the variation in polar distance allowable from mean or uniform rotative position in either direction. This information must be furnished by the designer of the generator. It is also necessary to know the form of indicator card expected to be realized, and the weights of the reciprocating parts of the engine, also for exact determination, the moment of inertia and center of gravity of the connecting rod Mr. Keilholtz has shown the method of obtaining curves showing the velocity of any point on the fly-wheel at any position of the stroke, also any point in reference to mean position or that due to uniform rotation.

The writer believes, however, that graphic methods can be used to much greater extent in the determination of these curves, and had hoped to be able to submit diagrams showing the methods employed. The time allowed, however, has been insufficient to do this. The graphic methods give much greater clearness of perception in estimating the value of the various modifications of design; for instance, the determination of which crank shall lead, the high or low pressure; and in difficult cases it is readily determinable whether some other crank angle than 90° will prove sufficiently beneficial in reducing disturbances to make it advisable to adopt this arrangement.

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It is usually the custom to deduce curves showing velocity variation and space variation for half, and full load and 50% overload, using, in determination of fly-wheel weight that one of the three space variation curves which gives the maximum result. In determining this curve of space variation, the mass of rotating parts can be conveniently taken as unity at the crank pin, and by simple proportion the maximum variations found can be reduced to the required amounts by the addition of mass at this point. It is then easy to reduce the mass at the crank pin to an equivalent mass at the fly-wheel rim, and thus the fly-wheel weight is adjusted to the requirements of the generator.

In practice, variations in steam distribution and other accidental causes introduce irregularities not allowed for in preceding calculations, to meet which an addition or safety factor of 30% to 50% is used in determining the weight of fly-wheel.

II. The type of governor used is important, because

(*a*) It must be readily adjustable in characteristics to meet the varying requirements of different voltages and frequencies, and to provide for the closest regulation consistent with proper division of loading between two or more machines.

(*b*) Two or more governors must be readily brought into synchronism as regards rate of decrease of speed with increase of load.

(*c*) The governor must be readily adjustable as regards damping or dash-pot effect.

(*d*) It must have sufficient power to retain control of the speed even under considerable dash-pot resistance.

(*e*) It must be adjustable for speed from the switchboard, to provide, first, for equalizing the speed of an unloaded unit with those carrying the load, in order to get the units into step; second, to make the unloaded unit assume its share of the load after putting it into step; third, to permit of relieving a unit from load so that it may be put out of service.

As concerns the low or medium speed engine with automatic trip cut-off, the inertia governor, belted or geared to the engine shaft, seems to possess all the above characteristics in a marked degree, its great power and rapidity of action, even under considerable dash-pot resistance, permitting of reducing the fly-wheel to dimensions sufficient to meet the requirements of the generator as previously explained, no addition of weight to the fly-wheel being necessary to give time for the governor to act.

The lighter the fly-wheel, the less the intensity of the pendulum effect, described by Mr. Emmet, and the less the resistance necessary to apply to the governor in the shape of dash-pot resistance. Dash-pots which release the governor, in case of tendency to motion of the governor weights, continuing for an appreciable time, as described by him, are undoubtedly the most generally effective.

The apparatus most satisfactory for varying the speed char-

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acteristics of a governor consists of a simple reversing motor of the d. c. type, which screws up or down a spring attached to the governor weights, the motor being started, stopped or reversed from the switchboard by a simple switch. By this means the switchboard attendant is placed in entire control of the situation.

Of two-crank engines, the twin engine, non-compound, operates in parallel most easily. The cross-compound engine, by reason of the impossibility of accurately dividing the loads between the two cylinders, for wide ranges of load, is more difficult to operate. This is, however, now the favorite type and can be used without fear of necessity for excessive fly-wheels. The double tandem engine does not give the good results which it would seem to possess, on account of its greater complication. Vertical engines require larger fly-wheels than horizontals, as the weight of the reciprocating parts acting vertically downwards introduces an irregularity in the rotative forces.

Three cranks, theoretically, give a great increase of steadiness, which is diminished in practice by difficulties of steam distribution. All in all, economy of steam being considered, the horizontal cross-compound seems the best all-round type, with the vertical form second.

THE PRESIDENT:—Gentlemen, we would like to hear now from Mr. Seymour, of McIntosh, Seymour & Co.

MR. JAMES A. SEYMOUR:—When requested by Mr. Mailloux to make some remarks on our experience with engines suitable for operating alternators in parallel, it occurred to me that while this subject has come to be quite generally understood by engineers having a special interest in it as evinced by the thorough and exhaustive papers which have been presented this evening, there often seems to be a lack of accurate knowledge of the requirements necessary to successful operation among those who may be contemplating the purchase of such apparatus; and, together with the generator and engine salesmen, they quite often discuss the problem from mistaken view-points or with a feeling of uncertainty, notwithstanding the correct expositions of the subject which have been published. Therefore, it seems to me that in order to clear up the subject, some discussion of these popular misapprehensions is necessary.

One notion, not so common now as formerly, is that close regulation is the principal quality desired. The ordinarily accepted and proper meaning of the term "close regulation" relates only to the difference in the mean speed of an engine between full load and no load as affected by the control of the steam supply by the governor. The requirements in this line for this kind of service are not greater than for any other; in fact, some of the builders of alternating current machines are now recommending a somewhat more sluggish regulation than has been usual in direct current work in order to simplify the problem of dividing up the load properly between the parallel running units. Mr. Stein-

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metz clearly points out that with no change in speed the division of the load is indeterminate.

The difference in the requirements for the proper running of a single unit from the requirements necessary to run two such units in parallel is not generally understood. In the first case, in order to avoid trouble with subsidiary apparatus, there must be a certain approximation to uniform motion throughout the revolution. This is secured by increasing the balancing effect of the fly-wheel to the proper amount, which may be determined by the very complete method given in Mr. Keilholtz's paper. When two such units are thrown in parallel, the principal difficulty to be avoided is the hunting or surging of the generators. Some of the causes of this trouble seem to be less understood than anything else connected with the subject. As pointed out by Mr. Emmet, the heavy fly-wheels which are necessary for proper uniformity of rotation, as mentioned above, increase the chance of trouble from the hunting of generators. This is quite contrary to a popular idea that sufficient uniformity of rotation insures correct operation in parallel.

Of course, in one sense, it is true, that if two units run in parallel with the revolving parts of both, always within a certain deviation from the position of absolutely uniform motion, there can be no harmful surging; but as we use the term "deviation from the position of uniform motion," it refers only to the deviation of a unit running singly at some constant load between no load and full load, such deviation being due to the irregularity of the torque of the applied forces, and being limited by the balancing effect of the fly-wheel. The trouble is when two such units are put in parallel, the deviation may be found to have become much greater. This increased deviation is the "cumulative" deviation referred to by Mr. Steinmetz, and may be caused by the combined action of the governors and the "pendulum-like" oscillations described by Mr. Emmet. Since the effect of this oscillatory movement is to simultaneously retard the speed of one unit and quicken that of the other, the governor of the unit which is being retarded will act and will cause more steam to be admitted; while in the other unit the steam supply will be similarly diminished. It will be noted that the governors, in doing this, are only performing their normal functions as speed regulators. There is necessarily an interval of time between the commencement of governor action and the change of speed resulting from the effect of such action on the steam supply. This I will call the time interval of governor action. A corresponding time interval for the swing or half period of the pendulum-like oscillations of the governors will result in a reversal of the swing of each unit by the time the change of speed is effected by the governor, and therefore, in an impetus to the faster unit and a retardation of the slower unit. This will cause a building up of oscillations until parallel running is impossible. If the time

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intervals correspond, as above, the oscillations will be built up from even a very small displacement of phase, which may result from the machines not being initially thrown into exact phase, or from the allowable deviation from uniform motion of the engines, or from other causes.

The cause of surging is quite generally described as due to the hunting tendency of the engine governors. This is often not correct and gives a wrong impression as to the nature of the trouble. It is true that if the governors are over-sensitive and unstable, they will have a hunting tendency, which will cause surging even with direct-current apparatus. Surging of alternators may also occur with types of valve gear where the cut-off mechanism is so sensitive that slight periodic changes in its position easily affect the cut-off. This may be due simply to lost motion, to the effect of the steam valves on the governor, or to other causes. If the vibration period of the governor weights happens to correspond with the oscillation period of the generators, there will doubtless be an increased tendency to hunt. However, in some of the cases cited by Mr. Emmet where this trouble was first encountered, the surging persisted until the damping of the governor action in both engines was carried to a degree which nearly rendered the governor inoperative. Damping the governor of one unit did not prevent trouble with the other. If the surging had been caused by a harmonic vibration of the governor mechanism, it would seem that a lesser damping, or a damping of only one governor, would have broken it up. It was found necessary in one instance, however, to damp both governors with an ordinary dash-pot to such an extent, that, while the governor would regulate within 2% from full load to no load, when full load was suddenly thrown off, the momentary variation in speed was about 15%. The period of oscillation was observed to be about four revolutions, or two seconds. Any quick acting and sensitive governor will be sensibly affected by a change of speed lasting for half such a period, and the time interval of governor action must be just about right to cause a building up of the oscillation.

Mr. Emmet quotes Mr. Kapp as explaining that the period of oscillation of the revolving part of such units is a function of the synchronizing power and of the inertia of the revolving mass. What I wish to make clear is that where this period is long enough to permit of sensible action by the governor, and where the time interval of governor action corresponds to a half period, as before described, cumulative surging may necessarily occur, even with a perfectly stable governor, which cannot properly be said to have any hunting tendency. Periods long enough to cause this trouble are usually found only with lower speeds and heavy wheels, but these are necessary features for the very large units which are often called for by the kind of service to which alternating work is peculiarly adapted. An obviously sure

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remedy is to lengthen the time interval of governor action sufficiently to break up its cumulative effect on the oscillations.

Of course a governor is equally responsive to changes of speed, whether due to changes of load or to the oscillations referred to. As stated by Mr. Emmet, the impossibility of sufficiently delaying the action of the governor by the usual damping devices without ruining it as a speed regulator, led to the invention by Mr. Cooke of the time-delay dash-pot described by Mr. Emmet. This device allows the governor to respond to the least change of speed if persistent beyond the period of oscillation, but gives a heavy damping effect for a shorter period. With this device, it has been found necessary to lengthen the time interval of governor action to such a small extent, that the efficiency of the governor as a speed regulator is not appreciably lessened. U. S. patent No. 677,064 has been granted to Mr. Cooke covering this form of dash-pot. This fact should be published in the TRANSACTIONS of the INSTITUTE simultaneously with Mr. Emmet's paper describing this device; otherwise, the natural inference would be that it is public property. This would be unfair, both to any one who might wish to make use of it and to Mr. Cooke.

Mr. Keilholtz's paper gives a carefully worked-out method of determining the relation between the balancing effect of the fly-wheel and the deviation from the position of absolutely uniform motion. He also gives an interesting experimental determination from an actual case. Owing to the very small deviation obtained with the proper weight of fly-wheel for actual service, and to the very short time intervals, all of which introduce great difficulties in making correct observations, I think Mr. Keilholtz is to be congratulated that his ingenious methods resulted in such a very fair agreement between the measured and the calculated results.

In determining the deviation of engines designed for this service, we use the ordinary and very convenient approximate method described by Prof. Unwin and other writers, and employ a graphical solution throughout. This approximate method assumes the entire weight of reciprocating parts to be concentrated at the crosshead pin. I have determined the difference in results obtained by this approximate method and by the exact method given in Mr. Keilholtz's paper, starting with the turning moments given in the table of his paper, but substituting for inertia moments those obtained by the approximate method. The maximum variation, which is the sum of the maximum deviations ahead of and behind the mean position of uniform motion, is but 42/100 of one per cent. less by the approximate than by the exact method. I do not consider, however, that it would be safe to assume that the error would always be so insignificant.

Mr. Slichter in his paper discusses some formulas, based on the number of steam impulses, for determining approximately the deviation from the position of uniform motion, and rightly

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questions the accuracy of this method because it entirely neglects inertia effects. The period of steam impulses in an engine having two cranks 90° apart is one-fourth of the revolution, while the period of inertia, statical, and connecting-rod-angularity effects is one revolution. With a given acceleration the displacement varies as the square of the time. In this case, therefore, the acceleration due to the inertia forces may in one sense be said to be sixteen times as effective as the acceleration due to the pressure of the steam. Even in cases where the piston speed is low, and the forces due to steam pressure are of very much greater magnitude than the inertia forces, the effect of the latter on the deviation will be considerable, and will increase with a rise in piston speed. Also, since, as Mr. Slichter points out, these different forces, when combined, generally tend to neutralize each other, thus making the crank box effort more uniform, a small variation in the relative magnitude of these forces may produce a much greater proportional change in the amount of deviation.

In short, it does not seem to be possible to determine, even approximately, the deviation of any engine without combining the torque curves of the different forces and finding by successive integrations the velocity and displacement curves.

It is possible to make the determinations for each crank separately. In combining them the effect of different crank angles can easily be investigated. I have in mind a large vertical cross-compound engine which has nothing about it out of the ordinary, except a rather high piston speed. The smallest maximum deviation was secured with the cranks 180 degrees apart or in opposite positions. With crank at right angles, one sequence of h. p. and l. p. cranks gave a smaller deviation than the opposite sequence, and with cranks 35° apart, nearly the same results were obtained as with cranks opposite. In this case the effect of steam impulses was so subordinate to the effect of the other forces, that when cranks were arranged to give two steam impulses a revolution, the deviation was smaller than when cranks were spaced to give four steam impulses a revolution.

When a low frequency is used, if the weight of fly-wheel is determined solely by the deviation requirements, it will not be heavy enough in some cases to serve as a proper balance wheel for the engine—having in mind the ordinary requirements for an engine working under variable load in any kind of electric service.

In regard to the method of throwing machines into step, some operating engineers prefer to do this by simply throttling down the light engine. Others prefer a speed-changing device by which the governor can be adjusted while running. Some such device is very convenient for dividing up the load between engines, since it avoids the necessity of keeping the governors always in accurate adjustment.

The first engines which we installed for this service were used

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with 300 k. w. generators running at 150 revolutions. Although, as mentioned before, the division of the load is easier with somewhat sluggish regulation, these engines were without difficulty thrown into step with each other by throttling, were run in parallel operation without hunting, and divided up the load properly with a variation from full load to no load of 1½ per cent. There was nothing special about the construction of the governors, no time-delay dash-pots were used, and yet there were no troubles from surging. The wheels were light, in view of the fact that the engines were of the tandem type. This helped out in the matter of surging, as did also the speed; the 60-cycle frequency was against it, however. Considerable attention is necessary to keep them in adjustment so that the load will be properly divided. These engines were installed without any conception of the troubles which have ultimately developed with units of larger size running at lower speeds. It would probably not be safe to count on duplicating this result.

Some time since, in connection with the installation of three Westinghouse two-phase, revolving armature, 500-volt, 60-cycle, 1,500 k. w. units running at 116 r. p. m., and one smaller unit of 750 k. w. capacity, after the contract for the engines was closed, we received a request from the engineering department of the generator contractors, asking for a fall in speed between no load and full load of 5%, for the purpose of aiding in proper divisions of the load. When the engines were started up, the consulting engineer for the company which was installing the plant stated that he had contracted for engines to regulate within 2%, and objected to 5%. Therefore, the engines were adjusted to give close regulation, in accordance with his view. These engines were provided with time-delay dash-pots, and also an attachment to the shaft governor for changing the speed. This device is operated electrically from the switchboard while the engine is running.

I give in full, reports of two series of tests made by the station operating force with these units. These tests show the performance of the units when running in parallel under different conditions, and indicate no trouble from dividing up the load, notwithstanding the close speed regulation by the governors. The first series is as follows:

First.—Our No. 3 engine was loaded up to about 1,200 k. w., the load being delivered to a water rheostat through the raising transformers. The No. 2 generator was then started up. By the use of the governor motors the speed of No. 2 was easily adjusted so that the phase lamps made one cycle in about one-half minute. The best speed of the phase lamps cycle for synchronizing is about one cycle in two seconds. When this speed was obtained the two generators were thrown in multiple on the high tension side of the raising transformers. About 200 amperes per phase (the generators are 500-volt, 2-phase) showed up on the ammeters.

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A slight adjustment of the field rheostat cut this current down to zero. Each generator is equipped with Westinghouse long-scale indicating wattmeters. The total swing of these wattmeters on the two engines was about 100 k. w. on each meter. The probable interchange of energy was not over 25 to 50 k. w. per phase, and made absolutely no effect on the voltmeters, nor was there any change of current which could be seen on the Westinghouse long scale ammeters. The governor motor of No. 2 was then speeded up, and in about one minute the load was balanced between the two machines. The No. 3 governor motor was then run in the "slow" direction while No. 2 motor continued to run in the "fast" direction. After about ½ minute the entire load was on No. 2, and a slight adjustment of the field rheostat, necessary on account of the regulation of the generator, cut the current on No. 3 down to zero. When the two machines had equal loads, the load was changed from as low as 200 k. w. per machine up to 1,000 per machine, and the loads were divided in exactly the same proportion at all points, and during this change of load the oscillations on the wattmeters were not more than 50 k. w. per meter, the time being 75 to 100 oscillations per minute, and did not apparently correspond to the revolutions of the engine. No attempt was made to get the engines in the same crank positions; in fact no observations were taken on this point.

Second.—A large engine and a small engine have been run together with about 100 k. w. total load, and the fluctuations of the wattmeters were about 100 k. w. per phase. These fluctuations were very rapid, perhaps 100 per minute, and rather more severe than in the above case.

Third.—We can run a large engine and a small engine in multiple with a considerable amount of load, and the wattmeter fluctuations are very moderate. The load can be shifted from one to the other without inconvenience, and nearly as easily, if not quite, as in the first case.

In no case do the ammeters show any fluctuations whatever, and the wattmeters, which are very delicate instruments, are the only means we have of telling that there is a fluctuation in the current; in fact, we consider the parallel running of our machines absolutely perfect, and, indeed, much easier than with the average d. c. plant. We have not, however, had any considerable amount of experience in this feature in actual running conditions other than above specified, since our load has been very light.

Following is the second series of tests, made several months later:

A test was made of two of our direct connected generators running in multiple; machines Nos. 3 and 4 were used. The engines and generators are described below. These machines were put in multiple on the high-tension side of raising transformers at 11,000 volts, and under the following conditions no

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fluctuations whatever in the ammeters could be seen, and the fluctuations indicated by wattmeters were *not more than 100 k. w. in any case.* All instruments were of the Westinghouse long scale type.

No. 1. Two machines with both phases in multiple at no load.

450 volts.

Current zero on both phases.

No. 2. Connections the same as No. 1.

1,000 amps. lagging current on each phase, caused by intentionally disproportioning the field current.

No. 3. Connections the same as No. 1.

450 volts.

200 amps. on each phase.

100 k. w. positive on each phase of No. 3 machine. 100 k. w. negative on each phase of No. 4 machine, caused by intentionally reducing the speed of one engine and increasing the speed of the other.

No. 4. Machines in multiple on one phase only.

450 volts.

Current 0.

No. 5. Machines in parallel on one phase only.

1,000 amps. caused by intentionally disproportioning the field current.

No. 6. Machines in multiple on one phase only.

450 volts.

200 amps.

100 k. w. positive on No. 3. 100 k. w. negative on No. 4.

No. 7. Machines in multiple on one phase only.

450 volts.

1,200 amps. on No. 4. 800 amps. on No. 3.

600 k. w. on No. 4. 400 k. w. on No. 3, caused by dropping the plate in water rheostat.

No. 8. 450 volts.

No amps. on No. 3. 2,000 amps. on No. 4.

No k. w. on No. 3. 1,000 k. w. on No. 4, caused by intentionally raising the speed of No. 4 and lowering the speed of No. 3, while the plates were in resistance tank, as in No. 7.

No. 9. Same as in No. 8, with generators alternated. Without changing the field rheostats from their position, as in No. 8, but having caused the electrical speed motors to throw the load onto No. 3, taking it all away from No. 4, a current of approximately 100 amps. appeared on No. 4, and a slight adjustment of the field rheostats was necessary to bring this to zero.

No. 10. Machines in multiple on both phases.

450 volts.

Between 0 and 50 amps.

0 to 50 k. w.

One 400 k. w., 500 v. rotary running at Eighth street sub station and resistance tank plates having been removed.

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No. 11. Same as No. 10, with two 400 k. w., 500 v. rotaries at Eighth street. Under this condition the rotaries at Eighth street showed no fluctuation whatever in their current, while with the single generator running at light load there was a fluctuation of about 200 amps. in the nature of "pumping."

The d. c. voltmeter on one rotary, with one engine running light, varied about 5 volts in time with the engine stroke. With two engines, one rotary showed a fluctuation on the d. c. voltmeter of less than 1 volt, and 2 rotaries on 2 engines showed no fluctuation of the d. c. voltmeter. Five observers at the switchboard failed to note any fluctuations in the meters when the two 400 k. w. rotaries were started and thrown into synchronism with the two engines, nor could any current be seen nor any change in the wattmeter fluctuation while the rotaries were operated or disconnected.

No. 12. After shutting down No. 4, No. 3 was operated on the water rheostat with 1,000 k. w. of load, the boiler pressure being 125 pounds. The difference in speed between it and No. 2 generator, which was carrying the commercial load, was shown by the synchronizing phase lamps to be about 15 cycles per minute, No. 3 being this much slower than No. 2. The circuit-breakers of both phases were opened under this condition of load, and the phase lamps made 20 cycles and slowed down to about one per minute, thus showing that the engine did not vary from the other a single revolution while having 1,000 k. w. thrown off. This test was repeated three times with identical results.

Substantially the same results are obtained with the General Electric machines of the same capacity at Boston, referred to by Mr. Emmet, and at other installations where these time-delay dash-pots have been used.

Mr. C. F. Scott:—Mr. President, in the consideration of the parallel running of alternators, there is one point which, while it has naturally been evolved in the various papers and discussions this evening, has not been brought out with the force which seems to me desirable. It is the fundamental difficulty in the parallel operation of alternators, which does not exist, for example, in the parallel operation of direct-current machines. It is the very great difference in the amount of power passing through each alternator caused by a slight difference in the angular positions of their armatures. If two direct-current machines are driven in parallel the machines may surge back and forth through a certain angle, but they will each be delivering practically constant power to the circuit. On the other hand, if two alternators running in parallel attempt to surge a little, the one which falls back may lose its whole load, and the one which is forward may take all the load.

It is quite common to consider this problem of alternator running with particular reference to the cross currents, and the impedance factors, and the wattless currents, and the oscillation, and

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the fly-wheels, and other things. But the system primarily is a power system; the purpose of the whole plant is to furnish power, and the alternators themselves are simply the instruments for receiving the power of engines and transmitting it to a circuit. For illustration, we may consider two similar power systems, one of which has the electric elements, and the other has not. The electric system, which is shown in Fig. 1 has two similar engines driving alternators which have wires coming down to bus-bars which supply a load. The second system, which is shown in Fig. 2, has two engines like the others, which drive gear wheels and the gear wheels mesh into pinions on a shaft. That shaft by a pulley and belt drives a load. In both cases engines transmit power through some instrumentality to a common load. In both cases the engines must run at the same average velocity. If one of the engines with gears tends to advance a little it simply relieves the other engine of load; it takes the load itself. If there be slight flexibility in the shaft joining the two, a slight variation in angular position is possible, but when there is any variation in angular position the elasticity of the shaft tends

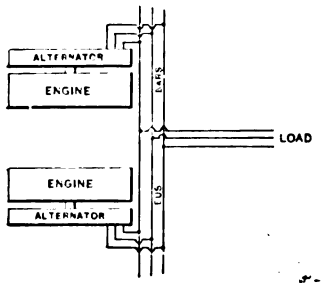

FIG. 1.

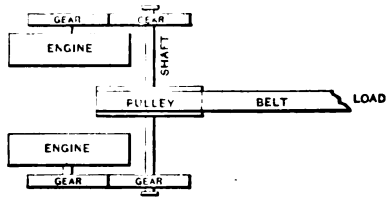

FIG. 2.

to draw back to the common and neutral position. If now, for any reason, one engine does advance a little, it takes more than its share of the load, and a very few degrees displacement will obviously remove all the load from the other engine. In this case the governor of the loaded engine—paying no attention to other things—may immediately proceed to get ready to supply more power; as it has been called upon for more power, it gets ready to deliver more. The other engine being relieved of its load, its governor begins to work the other way, because when less load is on the engine it gets ready to deliver less. The elasticity of the shaft may immediately remove the loads, the engine which lagged may now advance and carry the greater load, see-saw action begins to take place, and if the governors have a little swing of themselves it is easy to see how they can very soon set up an oscillation between the governors, shifting power first from

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one engine to the other. The analogy is obvious. The foregoing statements apply also to the electrical system in which alternators must run at absolutely the same mean velocity, but the elasticity, if you choose, of the electric circuit allows some little displacement. Now, if in the alternators we do get this condition, if wattmeters show vibration, and if there are currents flowing, we need not necessarily attribute the trouble to some fault in the alternator. The alternator simply disposes of the power which it receives. It unfortunately does not make any power itself, though it does insist on retaining a little of what it gets, and if wattmeters show variation, that must mean the alternators are receiving varying power from the engines which drive them, which will generally indicate that the supply of power to the engines from the steam is also varying. If two engines will not run alternators in parallel, it is likely that they would not be suited for driving a common shaft by gearing if the "elasticity" and the fly-wheel capacity of the two systems were the same. The problem of parallel running is a mechanical—an engine—problem.

By following out the mechanical illustration of the problem of synchronizing in respect to speed, phase, and other elements, I have often been able to get a very much clearer idea of multiple running. When any problem comes up, I try to divest myself of the intricacies of the flow of current and that sort of thing and get down to the simple mechanical analysis.

I spoke of the mutual oscillation of the governors. If they have a natural period of swing which corresponds to that of the elastic shaft or of the electric system they will assist in swinging the power from one engine to another. The interference of governors will be one method of cure. The governors may be given a period different from that of the other parts of the system by a different adjustment, and in that way they may cease to act in harmony and may cause an interference which will prevent any continued shifting of power. It may be that the governor may come in with an oscillation which will be a positive benefit by tending to break up in the other oscillations.

The matter of fly-wheels must be considered in two different connections. One relates to the angular variation from uniform speed during each revolution. The requirement is that the motion shall be sufficiently uniform so that in ordinary operation of machines there will not be excessive cross currents due to difference of phase between the e. m. f.'s generated by two alternators, as one engine is periodically a little in advance and a little back of the other, due to the irregular motion through the revolution. The fly-wheel must evidently be heavy enough, so that the flow of current shall be within reasonable limits.

On one hand, therefore, the fly-wheel must prevent undue variation being caused by the variation in rotative effort in the engine. On the other hand, it must prevent undue variation

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from external causes. The actual oscillation of a fly-wheel of an engine running alone depends on the character of the loads applied. Calculations such as have been given this evening apply to an engine supplying power to a uniform load, a dead load as we call it electrically. If it is supplying a synchronous load, a synchronous motor or a rotary converter, there is chance of hunting, in which the synchronous motor or rotary converter will take power intermittently. In that case there may be a reaction back on the generator, which will cause its angular position to vary from the uniform very much more than it does from a variation of the dead load. In some tests which I directed a year or more ago, this point was brought out quite clearly by a method of measuring the angular position, which was not as complete and elegant as that outlined by Mr. Keilholtz; yet it did very well under the circumstances. A small wheel was made to run at uniform speed. Slots in this wheel gave an intermittent ray of light at regular intervals, which was thrown on the surface of the fly-wheel, on which equally spaced lines were drawn. The conditions were investigated carefully, and it was found, from a little theoretical calculation, just what width the lines should appear if the wheel was running with absolute uniformity. I think the width of the clear white lines on black ground was about a sixteenth of an inch. If, then, the fly-wheel moved uniformly, these lines should all appear in the same place. If, however, it did not move uniformly, but was sometimes a little in advance and sometimes a little behind the mean position, these white lines would show a little above and a little below at different times, and as the speed was quite rapid they would appear in the shape of a band, which would be one-eighth, a quarter, half an inch in width, and by noting the width of this band the total amplitude of the vibration of the fly-wheel was determined. When running empty or carrying a load of incandescent lamps or induction motors, there was a certain slight variation in speed, which could be noted and read quite accurately. When a certain rotary converter was started, the motion continued about the same for a little while and then increased in amplitude, and soon ran out to quite violent proportions, showing the reaction of the rotary converter on the engine. This engine had a fly-wheel which was considerably lighter than another engine which was running other rotary converters of the same kind.

In certain other tests which have been made in another place, there were some tendencies to hunting, and a dash-pot was applied, and the oil in this dash-pot, in several tests, was made successively thicker and thicker, which improved the conditions, but they were still not perfectly satisfactory. Then the arm of the dash-pot was increased, and was made three or four times as great, as I now recall, and the successive grades of oil were then put in, with improving results each time. Each one of some half-dozen or more tests showed an improvement, all in the way

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of more effective damping, until the operation was fully satisfactory.

The matter of dampers has been referred to, and while the point has not been brought out specifically this evening, I have noticed at other times a very great tendency of the engine man to think that everything should be cured by something in the electrical system—usually dampers, more dampers; just as the electrical man thinks something is the matter with the engine and specifies dash-pots; more dash-pots!—which results in a kind of reciprocal action which keeps up a continual oscillation. The damper does not remove the cause of the disturbance, but does something which obscures it, something which prevents a cumulative action by giving a magnetic friction, a source of loss, and there are some cases in which conditions are very nearly balanced, where the damper may be of considerable use; and they turn the balance in favor of steady running. Dampers have been mentioned as being a source of loss in certain classes of dynamos. The damper will not be a source of loss if there is steady running, or if the magnetic circuit is pretty uniform. Primarily the

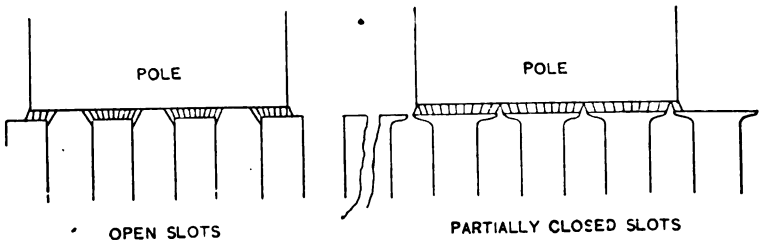

FIG. 8.

damper simply resists oscillation, and if there is uniform motion, and if the damper works effectively, it prevents the oscillation and therefore prevents the tendency to cumulative action and has no loss in it.

Returning to the mechanical analogue we may assume that the flexible shaft which is driven through gears by two engines is provided with a dash-pot. This dash-pot is so arranged as to resist angular flexure of the shaft. It will, therefore, damp the oscillations which may be set up, and thereby resist any tendency which may exist for periodic variation in the angular speed of the engines. The dash-pot acts only when there is oscillation, and does not consume energy unless there is oscillation.

The presence of dampers, however, may be a source of loss if the magnetic flux from the armature is not uniform. This may occur with armatures in which the slots between the teeth are pretty wide, so that the individual slot is wide in proportion to

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the air-gap. The magnetic field near the surface of the armature is not uniform—the magnetic lines come out from the teeth in little tufts; there is a great tendency for eddy currents in the faces of the field poles or in any copper damper so placed as to have these tufts of magnetism sweeping across it. If, however, the magnetic circuit is nearly closed, or partially closed, so that at the armature surface the slots or openings are very narrow, then the magnetic flux is substantially uniform, and that loss does not occur.

Teeth of the two kinds are shown in Fig. 3. The open slots produce a magnetic field which is not uniform, and which will, therefore, tend to produce currents in the pole face after the manner of an inductor dynamo. The partly closed slots give a practically uniform field.

Rotary converters are usually made with open slots, but as there is a large number of teeth in the armature of the rotary converter, and the slots are small, the width of the slot is not large in comparison with the air-gap, so that the magnetic field reaching the pole faces, or the shields, is substantially uniform.

THE PRESIDENT:—Gentlemen, we desire now to hear something more on another type of prime mover which has not been mentioned at all here; that is, the gas engine. Perhaps Mr. Nash can give us a few words on the gas engine and its regulation. As you know, a gas engine usually has a very bad reputation, of having a greater variation of speed than even the steam engine, and it would be interesting to hear what has been done in this respect.

MR. NASH:—Mr. President and Gentlemen: I replied to the invitation to address you to-night by saying that I was not sufficiently familiar with the subject to throw any light upon it. I can only say just a few words in relation to one method of governing which it seems to me may be applied to cure the conditions which we have here. I think all the trouble that is introduced by the vibration of the piston rod and by the angular action of the connecting rod can be cured by a device which we have used successfully in the direct-connected system; that is, by putting a massive governing device between the engine and the generator. That system is, in my opinion, capable of being carried out to considerable refinement, and I have only been thinking to-night a little along the lines which have been presented by the papers and by the speakers here. I can see that there is something more required in the refinement of regulation in the alternating current system than we have attempted, and I was in hopes that perhaps some of the makers of the Westinghouse engines could have given us some light upon how they have operated the Westinghouse engine, as they probably have had more experience. I am sorry to say that I have not to-night anything to add to the subject.

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THE PRESIDENT:—I voice the sentiment of the last speaker, that we would like to hear, if possible, something from the Westinghouse gas engine manufacturers who, as I know, have built very large gas engines, and most of us have seen one of them in successful operation at the Pan-American Exposition. We have a number of engineers present who have undoubtedly made the topic of to-night's papers the subject of consideration, and I would like to call on Mr. Mershon.

MR. RALPH D. MERSHON:—Mr. President and gentlemen of the INSTITUTE. The thing which has most interested me in the remarks this evening has been the question of possible electro-mechanical resonance, and it seems to me that it is a subject which, to some extent at any rate, has been avoided. The opinion has been expressed by some of the gentlemen presenting papers, that such resonance seldom if ever occurs in practice. Some others seem to think that it does occur at times. But in neither case, has any very good reason been given. If it is possible that such resonance should occur, then it seems to me that in such case the remedy which Mr. Emmet suggests for the prevention of hunting would not be effective, because, as I understand it, the remedy which he proposes is a remedy for the hunting difficulties resulting from the governors themselves, and could not affect troubles due to electro-mechanical resonance between the generators and the fly-wheels. Personally, I have never come across a case where trouble from hunting could be laid to electro-mechanical resonance, and for that reason, perhaps more than anything else, I am rather skeptical as to its ever existing in practice.

There is one point mentioned by Mr. Steinmetz, and incidentally by one or two of the gentlemen speaking after him, in regard to the stability of division of load obtained in the case of alternators in multiple by allowing a certain decrease in speed from no load to full load. This is a point of some importance which I do not think is understood by engineers generally, and is very easily and simply explained by a very simple diagram familiar to a good many of us, but not to some, perhaps. The instability of regulation due to equality of speed is well exemplified in the case of alternating generators driven by synchronous motors, and Mr. Stott, I believe, in a paper read some time ago before this institution, mentioned a case of that sort in which rather drastic measures had been resorted to in order to get the machines to properly divide their loads. As I said before, a simple diagram will show why a fall from speed will result in a stability in the division of load.

Suppose the regulation of the prime mover to be such that for equal increments of load the speed falls off equal amounts. If we plot loads on a horizontal axis and speeds on a vertical axis, the speed-load characteristic of the prime mover will be a straight line as for instance the line Y B in Fig. 1. Any point on this line corresponds to a certain definite speed, and a certain defin-

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ite load; that is, when running at any given speed the prime mover must be carrying a definite corresponding load, and vice versa. Suppose there are two prime movers whose speed-load characteristics are Y B and Y C respectively, and that each drives an alternator, the alternators being in parallel. Y B and Y C are shown as not identical, because it is not possible to adjust the governors of two prime movers so that there will be the same fall speed from no load to full load. Suppose the possible accuracy of identical adjustment to be equal to the vertical distance between the points B and C. Now the prime movers must run at the same speed since their alternators are in parallel. That is, the operating points on their respective characteristics must lie on a line *c b*

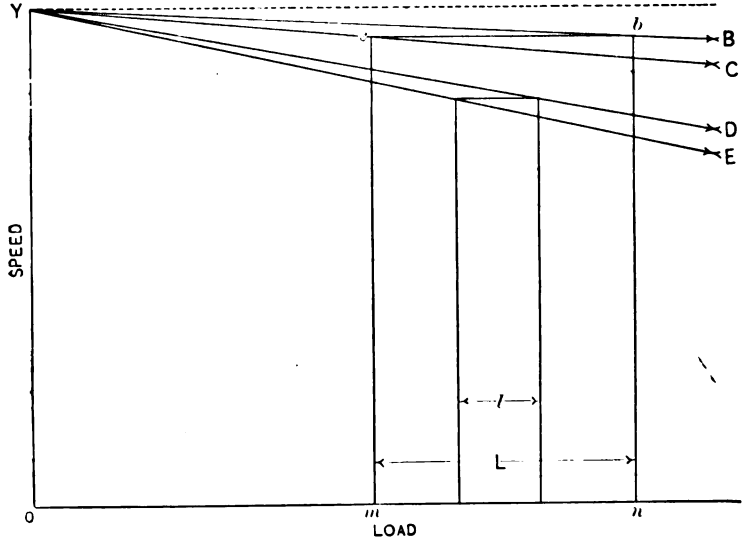

FIG. 1.

parallel to o X and the loads corresponding to the two operating points are o *m* and o *n* respectively. The difference of load carried by the machines is therefore L. Now let both governors be adjusted for a greater fall of speed, so that Y B becomes Y D and Y C becomes Y E, the vertical distance between D and E being the same as between B and C since the accuracy of identical adjustment remains about the same no matter what the fall of speed. In this latter case it will be noted that the difference in the loads carried will be only L. In general, the greater the fall in speed from no load to full load, the more nearly equal will be the loads carried by the prime movers.

Another point mentioned by Mr. Steinmetz was the fact that with an engine which governs very closely at light loads and not

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so closely at heavy loads, the division of load would be more stable at heavy than at light loads. I have known of one or two cases where, without making any close determination, apparently the speed characteristics of the engines, instead of being anywhere near straight lines, were something like those of Fig. 2. You can see that in a case of this sort a given accuracy of identical adjustment of the governors will result in a less difference in load on the two engines at heavy loads than at light loads. In the engines mentioned the division was not so good at light loads as at heavy. I might mention also that in some cases where a remedy had to be applied immediately, without any chance for experimentation or

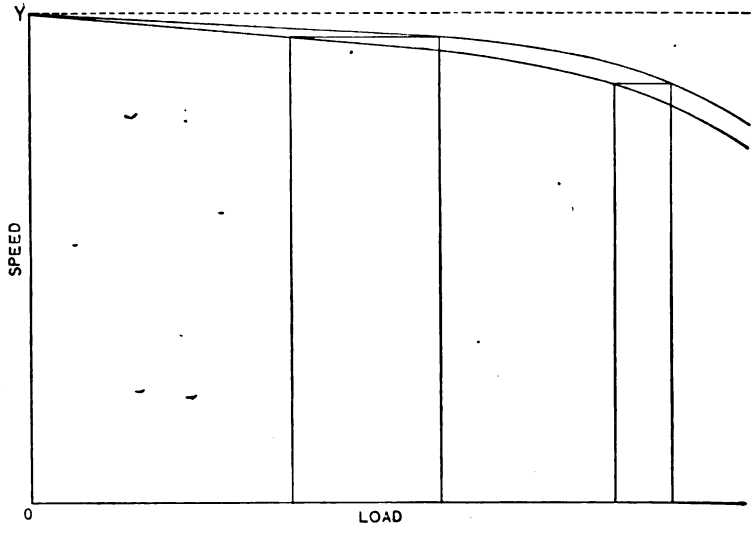

FIG. 2.

anything else, in the way of running in multiple generators which hunted with the governors adjusted as sent out by the engine builders, the trouble has been remedied by making the engines intentionally fall off a great deal more from no load to full load than they were originally intended to do.

Mr. Emmet mentioned as a probable influence in the prevention of electro-mechanical resonance that it was not likely, in most cases, that the natural period of the masses concerned would be anywhere near that of the pulsation of the engine; another reason it seems to me why there is not much chance for such vibration is the friction in the mechanisms itself which tends to deaden those vibrations, and which would correspond to the electrical friction, if we may so term it, that you would get by the use of shields or deadeners, or electrical devices of that sort for holding the machines in step.

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There was one point mentioned by Mr. Keilholtz in regard to the measurement of angular velocities and variations in angular velocities. He stated that it had been suggested that a direct current machine might be driven from the prime mover, the electromotive force of the machine opposed by a storage battery, and a voltmeter used to read the difference. It seems to me a much more accurate result might be gotten by using the direct-current machine and the storage battery, but using instead of the voltmeter, an instantaneous contact device in connection with a potentiometer.

As I stated before, the point which has interested me the most, and which I am sorry has not been more gone into, is the question of electro-mechanical resonance. I wish that the gentlemen had not limited themselves to a mere expression of opinion in regard to it. I should like to have more thoroughly their reasons for thinking that such will not exist, or such will exist, in practice. Some seem to think that it is more likely to exist if a heavy fly-wheel be used While I have not gone into the matter very deeply, my opinion is rather in the opposite direction and such experience as I have had has been in the opposite direction. I have had the trouble that Mr. Emmet has spoken of in regard to the surging of two machines which was traced to the governors. In a number of cases, in one case especially, this trouble was remedied by a change in the action of the governor, not by damping it at all, but by changing its period, and that change was effected by decreasing the value of the adjusting weight on the governor and at the same time moving it farther out on the lever, so that while the moment of the adjusting weight was the same its moment of inertia was changed, and with it the natural period of the governor.

MR. EMMET:—There are just a few words I would like an opportunity to say before I go. Mr. Scott has brought up a point that Mr. Mershon has also mentioned, about the possibility of getting over this trouble by adjusting the weight to the natural period of swing of the governor. I should think that would possibly result in benefit in many cases. Adjustments could be made which would tend to prevent this trouble, which is a somewhat exceptional trouble that does not occur in all cases, and which is liable to be broken up by almost any change in condition which would affect the period. But, generally speaking, it is not advantageous to have to use any special adjustments to accomplish this result. What we want is machines that will work in parallel every time. My experience has indicated that this method, which I have advocated, accomplishes the desired result every time. I have yet to find a case where it fails, although, as I have said, there may be such cases. I should like very much to have it thoroughly tried. I have heard of many cases of parallel operating alternators that had given trouble, and are giving trouble now, more or less, at certain times. It is very desirable for the whole

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electrical profession that, if a method of this sort has merits, it should be used and its merits or difficulties developed and acknowledged. We meet engine builders and people who are not in the electrical profession who do not know about these things. If electrical men do not agree, we cannot convince engine builders, and we will have very great difficulties in getting the practical results we desire. I am very anxious to hear of cases where this particular method, when properly applied, has failed.

There is one other point that Mr. Mershon brought up, that is the question of the possibility of electro-mechanical oscillation without actuation by the governor. We know, of course, that this trouble with the governor is simply an accompaniment of the tendency to oscillate electro-mechanically in a certain period by the generator. That natural tendency to oscillation is simply kept alive by the unequal delivery of the steam. I think, however, that there is a reason, which I stated briefly, and which possibly Mr. Mershon did not catch, for supposing that engines as a rule will not oscillate with their governors fixed; namely, that the engines are tied up to the reciprocating system, which has irregular friction. It is not a progressive friction, it is not a steady friction, but it is an irregular friction. Also irregular momentum which comes in jerks, and those jerks being unevenly distributed will not conform to any tendency to oscillation. We know that friction alone does not stop hunting in electrical operations. Simply applying a brake to a hunting synchronous motor will not stop its hunting at all. It apparently has no effect so far as I have seen. However, an interrupted friction, or any periodic disturbance that is not in conformity with the natural period of oscillation, will interfere with this hunting and may instantaneously stop it. Therefore, we would expect this irregularity of motion and load, imposed by the moving parts of the engine without steam, to cause a deadening effect and to discourage the electrical swing, which is a delicate, sensitive effect, with a fixed period, which, if disturbed, will disappear, as all waves will disappear, when the condition for their existence is not maintained.

THE PRESIDENT:—I think I can answer some questions raised by Mr. Mershon. I do not believe the heavy fly-wheel has any direct effect on the surging due to electro-mechanical resonance. But the vicious effect of a heavy fly-wheel is rather due to the increased tendency of the governor to overrun, because if the governor is caused to act by a temporary change of speed, due to a sudden change of load, while the temporary change of speed is reduced by the momentum of the fly wheel, the corrective effort of the governor in restoring the speed is retarded also; and therefore the governor continues to act after it ought to have stopped acting. Hence the fly-wheel has a similar effect to the momentum of the water in a hydraulic plant.

In regard to the question of electro-mechanical resonance, I have never observed it between alternators, but I have observed

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very pronounced cases of electro-mechanical resonance under conditions where any other source of surging was excluded; that is, one alternator driven by a water-wheel, and one synchronous motor or converter, in a case where the frequency was absolutely uniform, where there was no hunting between governors possible. This led me to an investigation which I made about two years ago but which I never quite completed. You will find in text-books that if you have one alternator and one synchronous motor connected by a line of certain resistance and inductance that the synchronous motor, in its electromotive force, adjusts itself in a permanent and fixed relation to the electromotive force of the generator, which relation depends on the load and the circuit and relative e. m. f's., etc. But theoretical investigation showed me that this generally accepted diagram does not represent the actual condition, but that the phase relation of a synchronous motor, operated from a single alternator at absolutely steady alternator frequency, is not definite, but may vary periodically synchronously with a variation of speed and the momentum of the synchronous apparatus, and that the period of this periodic variation of phase relation, which means periodic variation of current and voltage, or surging, depends on the constants of the electric circuit and the momentum of the moving masses; that is, this periodic variation is due to electro-mechanical resonance; and furthermore, I found that if no damping devices exist, consuming energy proportional to the variation of the speed from synchronism, then the amplitude of this periodic variation is either infinity or zero, depending on the conditions of the system. In the first case, surging occurs of cumulative character; in the last case the system is stable. Now, I have not gone any further in the investigation but shall carry it out when I have the time, since it gives the theory of electro-mechanical resonance and gives the conditions producing or eliminating it.

MR. MERSHON:—Any interaction which may take place between prime movers and their generators due to the governors is not what I understand as electro-mechanical resonance. Electro-mechanical resonance, as I understand it, involves only the moments of inertia of the prime movers and generators, the electrical properties of the generators and the speed as affecting the period of the pulsating forces on the piston. That is, true electro-mechanical resonance would exist independent of the governing mechanisms and would have place if the governors were put entirely out of action. Mr. Emmet considers the remedy he mentions to be a cure for all surging troubles, yet, as I understand it, he believes electro-mechanical resonance, as I have defined it, can exist. I do not understand how his remedy, affecting only the governor, can be a cure for that for which the governor is not responsible, and how, therefore, Mr. Emmet's remedy can be effective in case of true electro-mechanical resonance. The fact that this remedy has been effective in all cases where it was applied

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seems to me evidence that in none of them was the trouble due to electro-mechanical resonance, and strengthens me in my opinion, previously expressed, that it does not have place in practice, or if so, very rarely.

THE PRESIDENT:—It is customary at the end of a discussion to ask the readers of the papers to close the discussion by answering questions. The time, however, is so far advanced to-night that I believe we may dispense with that, and ask the authors of the papers to close the discussion in writing by communicating to the Secretary the answers to the questions which have been asked of them, and give us any further remarks they desire to make. I believe a motion to adjourn would be in order.

On motion of Mr. Mailloux, the meeting adjourned at 11.15 P. M.

[COMMUNICATED AFTER ADJOURNMENT BY MR. B. A. BEHREND.]

Permit me to add the following remarks in discussing the question of operating alternators in parallel:

The question of operating alternators in parallel requires the consideration of several factors, which are, to a certain extent, contradictory of one another. Let us first consider two or more alternators driven by water-wheels, the angular velocity of which may be assumed as uniform. In order to obtain as perfect parallel operation as possible, it would seem advantageous, at first sight, to use alternators so designed that the momentum of the revolving parts is as small as possible. In this case, if the prime mover showed a tendency to run faster or slower, the second generator could, on account of its small momentum, almost instantaneously respond to these changes in the speed of the first prime mover. But, at the same time, it becomes evident that the small momentum of the alternator permits of a larger variation in angular velocity of the prime mover, and so we see that diminishing the momentum of the rotating parts of the alternator would be advantageous in one respect and disadvantageous in another, and it becomes a question of compromise to strike a balance between the advantages and disadvantages. From the above reasoning it is also plain that a very large momentum would prevent the alternator revolving at a uniform angular velocity, from responding to the changes in angular velocity in the other alternator, the prime mover of which is, for the time being, lagging or leading, and therefore the exchange of synchronizing current might be greater with a heavy fly-wheel than with a light one, although the heavy fly-wheel would diminish the lack of uniformity in angular variation of the prime mover.

It is, of course, imperative to obtain an angular velocity as nearly uniform as possible. We may consider three different kinds of prime movers:

(1) Water-wheels and steam turbines.
(2) Steam engines.
(3) Gas and oil engines.

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The prime mover under (1) has practically a uniform angular velocity. The prime mover under (2) receives a number of impulses during one revolution which is dependent upon the number of cranks of the engine. The prime movers under (3) are the most unfavorable in regard to uniform angular velocity, owing to the explosions of the gas and the irregular crank-effort consequent upon it. In steam and gas engines driving alternators, it is a question of great importance to carefully consider the curve of

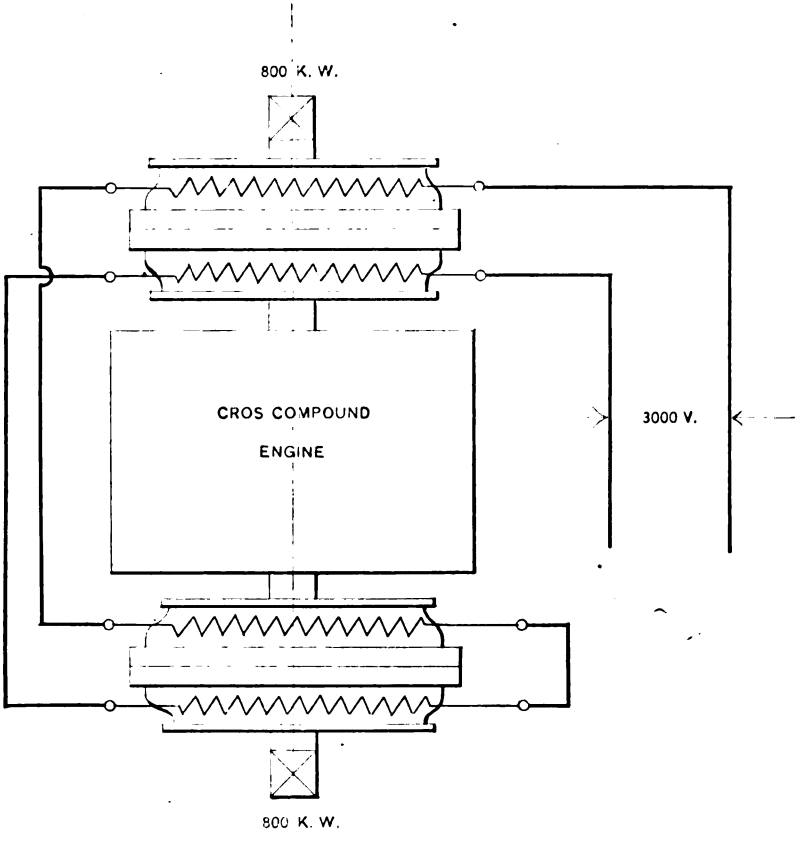

Diagram showing series connection of two 800 k. w. inductor generators on the same shaft. (Two phases only are shown.)

crank-effort and to make the crank-effort as constant as possible. This can be done by adopting two or more cranks properly displaced towards each other, and by carefully taking into consideration the momentum of the reciprocating parts and the influence on the diagram of crank-effort. If all these points are duly observed, no difficulty in operating alternators in parallel will be

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found, if driven by any of the prime movers mentioned under heads (1), (2) and (3). It may be well, however, to mention one phenomenon which is of paramount importance in operating alternators in parallel driven by steam or gas engines. The combination "alternator and fly-wheel" forms a dynamical system which is, in its behavior, analagous to the dynamical system formed by a spring and weight. Such a system has a natural period of vibration if once thrown into oscillation. Now let us imagine that the impulses from the prime mover will be so timed that their period is equal to the natural period of oscillation of the system "alternator and fly-wheel," and you will readily see that the oscillations, at first small, will be tremendously exaggerated by the impulses from the prime mover. In order to prevent this case of "resonance," to which Prof. A. Blondel first called attention in 1892, it is incumbent on the designer of the generator to determine the natural period of oscillation of his generator and to compare this with the "forced oscillation" caused by the impulses of the prime mover. These two periods of oscillation must be as different as possible. To illustrate:

In some 600 k. w. generators that I designed for the Bullock Electric Company, for the city of Nashville, the prime mover runs at a speed of 120 r. p. m. and is a cross-compound engine. The frequency of the engine impulses is therefore 8 cycles per second, while I computed the natural frequency of the dynamical system "generator and fly-wheel" to be 1.57 cycles per second. These figures show that there is no danger of resonance in this case.

The question of momentum in synchronous motors and rotary converters has been much discussed. It is entirely a question of compromise, and it is necessary, so to speak, to strike the golden mean between two opposing principles. A certain amount of momentum is necessary to take care of sudden overloads, short circuits, etc., but the less momentum we have, the more responsive are the synchronous motors or rotary converters to the variation in angular velocity of the generator and, therefore, the exchange of synchronizing currents is diminished in proportion. "Hunting" is a phenomenon that is inherent in all alternating current apparatus. Its causes have been discussed at length, and its prevention or diminution must be found in obtaining uniform angular velocity in the prime mover, and in avoiding rapid changes of load on the synchronous motors or rotary converters.

Steam engineers have worked over the problem of obtaining uniform angular velocity in the engines, and electrical engineers have used storage batteries in connection with rotary converters in order to avoid sudden changes of the load. But there are limits in both cases which can not be over-stepped, and therefore the *causes* of hunting can never be entirely avoided. The *symptoms* of hunting, however, can be greatly diminished by using damping coils which, though they involve a certain loss of energy,

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damp out of existence the oscillation that is set up by changes in angular velocity of the prime mover, or by changes of the load.

"Hunting" of alternators driven by steam engines is often caused by the "fluttering" of the governors. In this case the remedy is simple and consists in putting an effective damping device, as a dash-pot, on the governor.

I observed a very curious case in the early days of large engine-driven alternators. The Oerlikon Co. had built four 800 k. w. inductor generators running at 107 r. p. m. for one of the large Berlin central stations. Two of these generators, which were of the double inductor type, wound for 3,000 volts and 50 cycles, were driven by one vertical steam engine. The generators had a very small synchronous inductance; their design was a reaction against the generators of the Lauffen type, of high synchronous inductance, and therefore the cross currents between two armatures, very slightly offset, were enormous. The two generators, mounted on the ends of the same shaft, *could not be operated in parallel.* Without any load, the apparent energy of the cross-currents amounted to about 1,000 k. v. a. at normal excitation. The shaft not being absolutely rigid, and the engines being cross-compound engines, the impulses from the high pressure cylinder, and those from the low pressure cylinder, were not in synchronism, leading to tremendous surging and oscillation, so that at times a breaking of the engine shaft seemed imminent. Reactance coils were tried, but without any success. It struck me that it must be possible to connect the generators in series instead of in parallel, and in order to obtain again 3,000 volts, I had only one armature of each generator connected in series with the corres ponding armature of the other generator, so that we obtained the arrangement as shown by the sketch.

This remedy was perfect. The two independently driven sets of 1,600 k. w. each could be operated in parallel without any difficulty.

[Communicated after Adjournment by Mr. August H. Kruesi.]

We are indebted to Mr. Keilholtz for the results of an actual measurement of velocity variation, but it is regrettable that he does not feel sure of the value he gives. Such measurements are inherently difficult, and very few figures have so far been published. I know of some recent experiments in which the varying potential of a small direct current dynamo driven by the engine was measured by an oscillograph. The oscillograph seemed well suited to this purpose, but the fluctuation in potential, due to the finite number of commutator segments, even in the case of a smooth core machine, was found to be of even greater magnitude than the engine variations, so that the latter were completely obliterated.

The value of actual measurements of velocity variation of engines which have proved bad or just on the border line is

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great, first as a check on our methods of calculation, which can hardly be considered certain at present, and second, to ascertain whether or not the degree of uniformity in speed now demanded is not excessively rigorous and our fly-wheels unnecessarily heavy. There is probably no other accurate way to compare engines of various designs or engines having different fly-wheel capacities, and until such comparisons have been made between engines which give poor parallel operation and those which operate well, the determination of fly-wheel capacity will remain largely a matter of guess work.

It seems to be pretty generally agreed that the governor should be made responsible for parallel operation, and that "the tendency to hunting seems to be aggravated by the use of heavy fly-wheels." Mr. Keilholtz's figure of 11 mm. displacement on the periphery of the wheel is equivalent to 3.9° of phase for a 25-cycle, 30-pole alternator. Since the engine drives a direct current railway generator this amount of fly-wheel is presumably necessary for railway service, and it is desirable that no more should be necessary for an alternator, but we may be quite certain that the engine builder would have used much more. European engineers have practised parallel operation from low speed engines very extensively and successfully, and with relatively light fly-wheels.

We may arrive roughly at the sufficiency of fly-wheel in any case by finding the energy in foot-pounds stored in the wheel per k. w. and pole of the alternator, and multiplying by the number of cranks, making 90° or 120° angle, since for a given wheel the larger the number of cranks the less the speed variation will be.

That is, the figure of sufficiency $= J = \dfrac{w\, v^2 \times \text{cranks}}{2\, g \times \text{k. w.} \times \text{poles}}$

Analyzing nine recent European engines in this way, I find the average figures for nine low speed engines to be 200 ft.-lbs. per k. w. and pole, the smallest being 100 and the largest 250. Four large low-speed engines of one make, recently built in America, give an average of 500, the smallest being 485 and the largest 505. Are not our wheels too heavy?

[COMMUNICATED AFTER ADJOURNMENT BY E. W. MIX, OF PARIS.]

Considerable attention has of late been called to the problem of measuring conveniently the variation of speed during one revolution of a fly-wheel or revolving field of an alternating-current dynamo. The apparatus described herewith is very convenient for this work. The principle is the following:

A small disk having considerable inertia is driven by means of a flexible coupling at a practically constant speed by means of the fly-wheel under observation, while a light aluminium disk is driven in the opposite direction at a speed proportional to the

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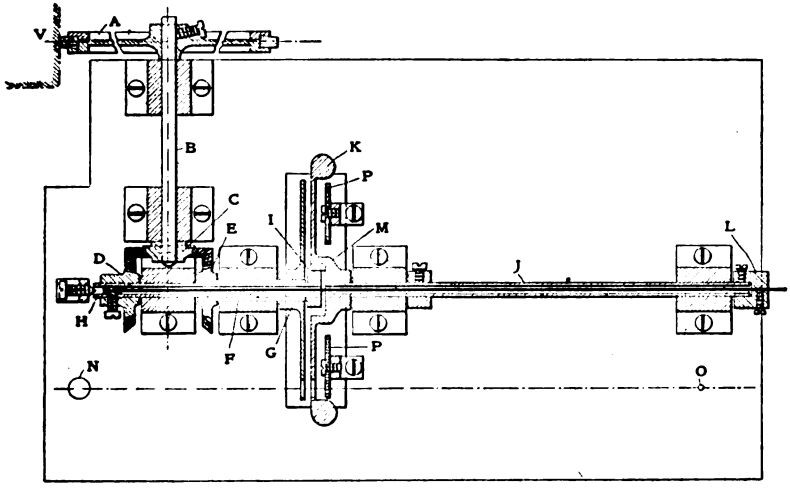
speed of the fly-wheel and obliged to follow all the variation of speed of the latter. These two disks are mounted side by side, with their axes in the same line, and a radial slit is cut in each of them at the same distance from the center. When the two disks turn at exactly the same speed these two slits pass one another at the same point in space, but should one revolve faster than the other the point of passing of these slits will be displaced in one sense or the other, depending on which disk is revolving the faster.

By placing a lamp on one side of the disks and an opaque screen on the other a spot of light will be projected on this screen and its displacement can be easily observed.

If now the aluminium disk be driven with an angular velocity, say 40 times as great as that of the fly-wheel, whose variations in speed are to be observed, and the disk with high inertia be driven by means of a flexible coupling from the same fly-wheel, the relation between the inertia of the disk and the flexibility of its coupling being such that the former will revolve at practically constant speed and proportion to the mean speed of the fly-wheel, then the spot of light on the screen will move back and forth through an angle 40 times as great as the angular variation of speed of the fly-wheel. By thus multiplying the angular variations the measurements can be made with great accuracy.

The figure shown herewith is made from a scale drawing of the apparatus as actually constructed.



Apparatus for Measuring Speed Variations.

In this figure, v represents a section of the rim of the fly-wheel whose variations of speed are to be measured. The small disk, or wheel A, made with as little inertia as possible, is

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provided with a rubber tire so as to be driven by friction against the rim of the fly-wheel. This wheel is mounted on one end of a shaft B, carrying at the other end a conical pinion C, which drives two other conical pinions D and E, having an equal number of teeth.

The pinion E is mounted on one end of a hollow shaft F, which carries at the other end the light aluminium disk G.

The pinion D is mounted on one end of the hollow shaft H, passing inside the shaft F and carrying at the other end a collar provided with a lug I.

The disk K, provided with a heavy rim, so as to give it considerable inertia, is mounted on one end of the hollow shaft J, the latter being mounted in line with the shaft F. The other end of J is provided with a collar L, which can be fixed on the shaft, by means of a screw, in any angular position.

A small steel wire passes through the two hollow shafts H and J, one end being fastened by a screw in H, the other being held in the collar L. By twisting more or less this steel wire by means of the collar L, the necessary turning moment for driving the disk K can be obtained.

Inside the cavity in the hub of the disk K is a little lug M which can come in contact with the lug I fixed to the end of the shaft H. By means of these two lugs the disk K can be brought up to speed without undue strain on the steel wire which normally drives it.

The slits in the two disks are shown in line with the points N and O, N representing a lamp and O the eye of the observer. P is a ground-glass circular scale divided into degrees of a circle on which the angular displacements of the spot of light produced by the passage of the slits in the two disks, one before the other, can be observed.

In case the rim of the fly-wheel under observation does not turn perfectly round it is necessary to make a flexible extension to the shaft B, on which the driving disk A is mounted so that this disk can follow the rim without being obliged to compress too much the rubber tire, as in the latter case the resultant circumference of the disk A would vary at different angular positions of the fly-wheel, and so produce errors of observation of the same order as the angular variation of speed to be measured.

Should it be desired to register the variation of speed this can be done by slightly separating the two disks G and K, and introducing between them a satellite pinion driven by two conical pinions, one mounted on each of the disks. An index carried by the axis of this satellite pinion can be made to describe a curve on a piece of paper driven before it at a uniform speed, as is done in a recording ampere-meter.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, November 22, 1901.

The 158th Meeting of the INSTITUTE was called to order at 12 W. 31st. St., New York City, with President Steinmetz in the chair.

THE SECRETARY:—At the meeting of the Board of Directors this afternoon the following associates were elected:

Name	Address	Endorsed by
CRAVATH, JAMES RALEY,	Western Editor, Electrical World and Engineer, 1139 Monadnock Block, Chicago, Ill.	W. D. Weaver. Ceil P. Poole. H. W. Blake.
CROSSMAN, GILBERT,	Telephone Engineer, Western Electric Co. 463 West St., residence 80 Washington Square E. New York City.	G. F. Atwood. O. A. Bell. G. A. Hamilton.
DUSENBERRE, GEORGE BROWN,	Assistant to Fourth Vice-President, Westinghouse Electric & Mfg. Co., Pittsburg; residence, Englewood Park, Pa.	L. A. Osborne. C. A. Terry. C. F. Scott.
EASTMAN, GEORGE NIAL,	In charge of Testing Laboratory, Chicago Edison Co., 139 Adams St., Chicago, Ill.	F. B. Badt. Saml. Insull. P. B. Woodworth.
FREUDENBERGER, WILLIAM	KAISER, Chief Electrician, The Colorado Fuel & Iron Co., residence, 209 E. Evans, Pueblo, Col.	A. E. Maccoun. H. B. Shaw. E. Friedlaender.
HAMILTON, RALPH BERGEN,	Manager, The Packard Electric Co. Ltd., St. Catharines, Ont.	A. A. Dion. Frederick Bedell. John Murphy.
HOOPES, MAURICE.	Mechanical Engineer, J. G. White Co., 29 Broadway; residence 30 East 39th St., New York City.	H. A. Lardner. W. B. Potter. H. J. Ryan.
KING, HARRY R.,	Electrical Engineer, Western Electric Co., Chicago, Ill.	H. S. Carhart. B. J. Arnold. H. H. Wait.
LANPHIER, ROBERT CARR,	Superintendent and Electrican, Sangamo Electric Co., Springfield, Ill.	L. Gutmann. W. S. Aldrich. William Esty.
LUDVIGSEN, HANS VALDEMAR,	Electro Chemical Engineer, Blaagaardsgade 17, Copenhagen; residence Strandvejen 119, Hellerup, Denmark.	W. J. Hammer. C. P. Steinmetz. R. W. Pope.

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NESBIT, JOSEPH NEWTON	GRAY, Superintendent Winding Department, Warren Electric Mfg. Co., 416 Fulton St., Sandusky, Ohio	W. J. Hammer. R. W. Pope. J. P. Jackson.
O'BRIEN, ALBERT DALLAM,	Assistant N. Y. & N. J. Telephone Co., 15 Dey St., New York City; residence 151 Columbia Heights Brooklyn, N, Y.	E. J. Houston. W. C. L. Eglin. A. E. Kennelly.
POTT, ARTHUR HENRY,	Consulting Engineer. with Preece and Cardew; residence 81 Cornwall Gardens, S. W. Queensgate, London, England.	W. H, Preece. W. M. Mordey. R. W. Pope
REUTERDAHL, ARVID.	President and Chief Engineer, The Reuterdahl Electric Co.; residence, 366 Willard Ave., Providence, R. I.	W. J. Ballou. R. W. Pope. W. J. Hammer.
RUCHGABER, ALBERT FELIX,	Draughtsman, Rapid Transit Subway Construction Co.; residence 373 Carlton Ave., Brooklyn, N. Y.	C. E. Skinner. R. W. Pope W. J. Hammer
RUSSEL, EDGAR,	Capt. Signal Corp, U. S. A. War Department, Washington, D. C.	Samuel Reber. T. Wolcott. E. B. Ives.
SCHILDHAUER, EDWARD,	Engineering Department Chicago Edison Co., 139 Adams St., Chicago, Ill.	Samuel Insull. D. C. Jackson. B. Frankenfield.
SCHMIDT, LAMBERT,	President, The Lambert Schmidt Tel. Mfg. Co., 325 Broadway, New York City; residence 138 Schippen St., Weehawken, N.J.	Samuel Reber. T. Wolcott. E. E. Ries.
SOREN, TOWNSEND HODGES,	Electrical Engineer, General Electric Co., Schenectady, N.Y.	C. P. Steinmetz. E. W. Rice, Jr. H. G. Stott.
TANNATT, EBEN TAPPAN,	Managing Civil and Electrical Engineer, The Oahu College Trustees; P. O. Box 92 Honolulu, H. Ty.	W. J. Hammer. R. J. Pratt. C. P. Steinmetz.
VAN DYCK, WILLIAM VAN BERGIN,	Electrical Engineer and Contractor; residence 489 Manhattan Ave., New York City.	J. J. Bellman. G. A. Thomson. F. B. Crocker.
WEYMOUTH, THOMAS ROTE,	Electrical Engineer, International Hydraulic Co., 40 Wall St.; residence 80 Washington Square E., New York City.	R. D. Mershon. C. Van Deventer. C. C. Chesney.
ZWIETUSCH, EDWARD OTTO,	Electrical Engineer Telephon Apharat Fabric Petsch, Zwietusch & Co., Salzufer 7, Charlottenburg, Germany.	J. J. Carty. G. A. Hamilton. O. A. Bell.

Transferred from Associate to full Membership:

Approved by Board, of Examiners, October 11th, 1901.

CARL L. DE MURALT, Baden, Switzerland.

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THE PRESIDENT:—Gentlemen, the topic for to-night's consideration is "Systems of Electric Light and Power Distribution." The problem of electric light and power distribution essentially consists in supplying from one primary generating station electric power to a number of customers in a form suitable for their demands. In its theoretical and simplest form a system of electrical distribution consists of the generating station and a system of distribution conductors, and in addition thereto controlling apparatus in the generating station and metering appliances at the customers' premises. Such stations and distribution systems of the theoretically simplest form, but still of very large magnitude, utilizing continuous current, are even in our day in successful commercial operation.

Since, however, according to the different applications, the electric energy is required in different forms, as for incandescent lighting, arc lighting and electric railways, etc., it becomes necessary either to install a number of separate and distinct distribution systems for the different forms of electric power, or to introduce into the system tranforming apparatus. By the introduction of transforming apparatus the system of generation becomes more or less independent of the system of utilization, and hereby then the problem is created for the electrical engineers to decide which system of electrical distribution is the most suitable in each individual case. The conditions underlying the decision of the problem are, on the one hand, the reliability, efficiency and safety of the system as regards generation, transmission and distribution, and on the other hand, the utilization of as large a part of the total power as possible in the form generated, or with only few transformations or conversions.

Still more complicated the problem becomes in some instances by the introduction of extraneous conditions depending on circumstances not directly connected with the distribution, as for instance, where the power is received from a long distance over transmission lines, and by the limitations incident to long distance transmission, certain restrictions are imposed upon the generation and transmission of power. Hence to utilize as large an amount of power as possible without too many conversions or transformations, it becomes desirable to use the electric energy in a form which may not be as suitable or desirable as if the power were generated on the premises. It can be seen that—by giving here the one or the other feature a slightly greater prominence by either compromising between heterogenous conditions, or by following one extreme without transformation and transforming the electric power for the other extreme—very different solutions can be reached of the same problem with almost the same satisfaction. Therefore it may not be astonishing that different engineers of equal prominence may reach, under individual conditions, exactly opposite points of view, although

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naturally in a considerable number of features you will find a general agreement of opinion existing.

Since we have quite a considerable list of papers for discussion to-night, and the promise of a number of prominent speakers, it will be absolutely essential to restrict the time devoted to each paper to a maximum of ten minutes, and therefore not to read the paper *in extenso*, but in abstract.

I call upon Dr. Kennelly to make an announcement.

DR. ARTHUR E. KENNELLY:—Mr. Chairman and gentlemen: A circular letter has been issued, signed by Mr. Goddard, as the Secretary of the New England Insurance Exchange, in which certain additions are suggested to Rule No. 39 in the existing National Code, for constant potential circuits of over 3,500 volts potential. The suggested changes are: First, that such circuits—that is to say, extra high pressure circuits—should not be allowed overhead within 75 feet of any building, with a certain reservation for special cases; and, second, that they should not be allowed on the same poles with other wires, nor on the same side of the street or of the road with pole lines carrying other wires.

A copy of this letter having been sent to the INSTITUTE, a committee has been appointed by the President, consisting of Mr. Hammer, Mr. Sinclair and myself, to meet the members of Mr. Goddard's committee at their meeting on the 3rd of December next, and it is the wish of the Board of Directors, as expressed at their meeting to-day, that all members of the INSTITUTE interested in this rule, or in any other rules of the National Code which may call for modification, should communicate with the Secretary of the INSTITUTE, and express their views upon the subject in writing, with a view to the general consideration of the matter on the part of the INSTITUTE. It seems unlikely that such general consideration can be effected by the 3rd of December next, and it may be necessary to request the committee of the Board of Insurance Underwriters to extend the time for taking action, if such extension be possible; but I am asked to extend, on behalf of the President and the Board of Directors, the request that all members interested in this proposed new rule of the National Code should communicate with the committee through the Secretary of the INSTITUTE.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, at New York and Chicago, November 22, 1901.

THE DISTRIBUTION BY THE THREE-PHASE SYSTEM AND THE OPERATION OF SINGLE-PHASE CIRCUITS BY IT.

BY W. L. R. EMMET.

Since the single-phase alternating distribution preceded the use of polyphase currents there has naturally been a tendency to continue its use, and a full appreciation of the advantages of polyphase currents has not been acquired by many of the practical men who handle distribution problems. The first uses of polyphase currents were for power alone, the old single-phase lighting systems being unchanged. As time has gone, however, the use of single-phase apparatus has steadily diminished, and the production of polyphase apparatus has increased; and although there is still some demand for single-phase generators, an investigation will show that the best informed electrical engineers have now discarded them altogether.

An extensive experience with a single-phase, two-phase, three-phase and other apparatus has led me to believe that for almost all purposes of lighting and power distribution the three-phase winding is the most desirable for central station generators, and that two-phase and single-phase windings have, in the great majority of cases, no good reason for existence.

It is not necessary to enumerate all the advantages of the three-phase system, but it may be said that among the reasons for its universal adoption are that the three-phase generator is better than the two-phase generator for single-phase operation, where single-phase operation is required, and, further, that the

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three-phase generator when used as a single-phaser, is practically as good and as cheap as it would be if it had been designed particularly for single-phase uses. Thus it can meet the two-phaser or the single-phase on equal terms on their own field and at the same time can afford its own special advantages.

When a three-phase generator is to be operated on a single-phase circuit it is generally desirable to use a "Y" connected winding, although with certain types of windings the delta connection will give equally good results With such a winding the three-phase machine, as ordinarily designed, will carry from 75 per cent. to 85 per cent. of its rated load in single-phase current between two conductors with the same heating which would be produced by operation at its rated capacity with balanced three-phase current. If motors or rotary converters are connected to a three-phase generator which is operating with single-phase load, these motors or converters will tend to equalize the load between phases and thus may increase the capacity of the system. When a three-phaser is partly loaded with single-phase currents between two of its wires the unused phases may naturally be loaded with other single-phase currents, thus giving various degrees of unbalancing between the three phases and, with normal heating, will vary from 75 per cent. to 100 per cent. of the total three-phase capacity.

The statement that the three-phaser will carry 75 per cent. of its rated load in single-phase current frequently leads the customer to ask: "Why should I buy such a machine to deliver single-phase current when I can get a single-phaser which will deliver its full-rated capacity with normal heating?" The answer to this question is that the three-phaser designed for a given single-phase output has about the same size and cost as the machine designed for single-phase alone, the apparent inconsistency lying in the fact that a three-phaser for a given output is cheaper and smaller than a single-phaser.

While purchasers of three-phase generators have frequently made special demand for large single-phase capacity, there are in point of fact, very few cases where it is necessary or desirable to operate three-phase machines exclusively on single-phase load. Companies that operate single-phase circuits can almost invariably divide their circuits roughly into groups, putting some of them on one phase and some on the others. The only portion of a lighting company's load, which cannot be advantageously

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divided between the phases is the low tension, interconnected distributing system, if such a system is used. Even where such systems are used they never include the whole lighting distribution of the company, and there will always be outlying circuits which can be operated from other phases. There are also, in most cases, transformers for arc lighting and other kinds of single-phase load which can be put upon the least used phases, and which will thus tend to help out the balance of the system. Many purchasers think that it is necessary to buy a single-phase generator because they use single-phase circuits, whereas the approximate division of these circuits between the phases would involve no difficulty whatever.

Since the normal single-phase capacity of a three-phaser is about 80 per cent., since all motors and rotary converters tend to equalize the balance, and since there is always scattering single-phase load which can be conveniently put upon the lightly loaded phases, we may practically consider that the three-phase generator can be used at its rated capacity on any system.

If the three-phase generator is operated with single-phase load, or with seriously unbalanced load there will generally be a marked potential difference between its phases. The phase carrying load will show the drop in potential which such load would ordinarily occasion on a similar single-phase machine; one of the disused phases will generally show a higher voltage and the other a lower voltage. With machines of good inherent regulation, such as are now generally used for lighting purposes, these differences are small and can readily be taken care of by regulators in feeder circuits. Where three-phase generators are operated on single-phase, three-wire distributing systems, the general practice is to regulate the generator to give the desired voltage on the three-wire system, and to control by regulators the voltage of circuits connected to the other phases. The variations of voltage on these other phases may, in some cases, be actually a convenience, since between the three phases a voltage can often be selected which will nearly suit the requirements of any feeder.

Two systems of low tension distribution for lighting are used and recommended in connection with three-phase generators, viz.: the single-phase, three-wire system, and the three-phase, four-wire system. When the single-phase, three-wire system is used, the generator is generally somewhat unbalanced by the large demand for single-phase current which the three-phase wire system creates,

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and the voltage is regulated with reference to the needs of the three-wire system. The primary circuits are so arranged as to deliver power through transformers to low tension network. The transformer secondaries are provided with three leads, one for the neutral and one for each of the outside wires. Since the drop in high tension lines is small, and since transformers can be put wherever they are needed, it is easy to arrange an alternating three-wire system in such a manner that it will give very perfect voltage distribution in all parts of the area which it supplies. In direct current, three-wire systems, we naturally have to deal with large and variable feeder losses, which, in spite of the most

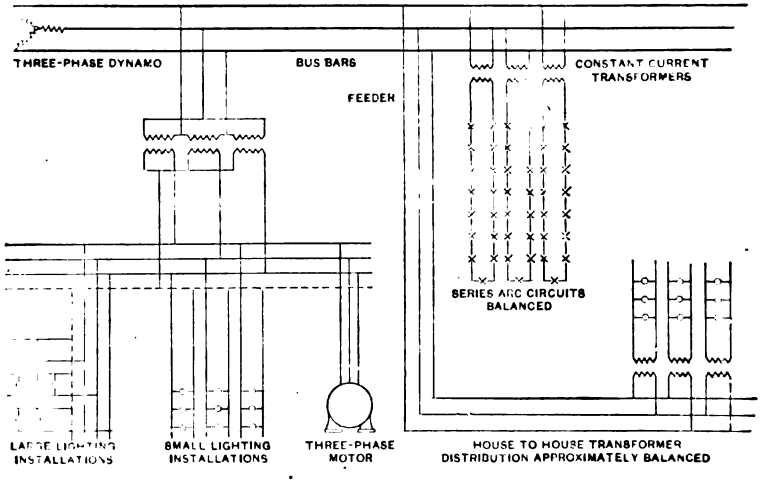

FIG. 1.—Four-wire three-phase low tension system.

careful arrangements, must seriously interfere with the maintenance of good regulation. In alternating three-wire systems the regulation should, with intelligent handling, be practically perfect.

The other method which is available for low tension distribution with three-phase dynamos is the four-wire, three-phase system. This system is supplied from groups of transformers, with three in each, their secondaries being connected in "Y" from a neutral. The secondary voltage of each transformer is that suitable for the lamps which it is desirable to use. In action, this arrangement is equivalent to the ordinary three-wire system, except that it has three branches and a neutral instead of two branches and a neutral. The copper economy is practically the same in both, the advantage being slightly in favor of the four-

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wire, three-phase system, since the neutral need not be quite so large. This system also has the advantage that its outside wires are available for operating motors. Another advantage is that it affords a balanced load to the three-phase generators, if the four-wire system is kept in balance.

The arrangement of these methods of secondary distribution is illustrated by Figs. 1, 2 and 3. From these diagrams it will be

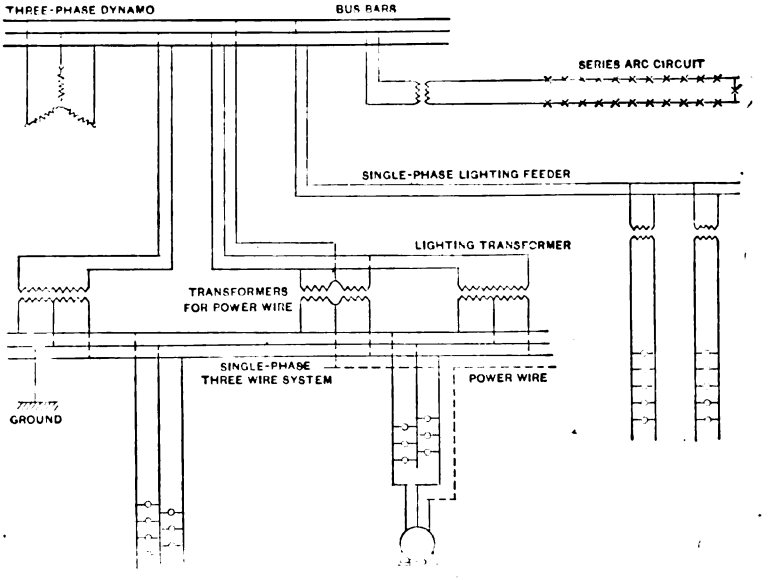

FIG. 2.—Three-phase generator with single-phase three-wire low tension system.

seen that it is necessary to use four wires with either, if motors are to be operated. Where the single-phase, three-wire system is used, it is necessary to run a separate power wire which can be energized from a transformer, and which, with the outside wires of the three-wire system, affords three-phase currents for operating motors.

The four-wire, three-phase system cannot be advantageously used in all cases. Where it can be consistently used on a large scale it is probably the most desirable method of secondary distribution. It should not be used, however, where the conditions are such that the three-phase system must be seriously unbalanced by arc light transformers or other unavoidably unbalanced load. Generally it is not desirable unless its arrangement is complete and the whole plant is arranged and operated with reference to its use. In the rearrangement of existing plants it will gener-

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ally be expedient to use the single-phase, three-wire system, operated from three-phase generators, as described above.

In distributing electricity over considerable areas it is desirable to keep in view certain general principles in order that proper voltage distribution may be obtained. Some of the variations which affect voltage regulation are controllable from the station, while others are beyond such control, and conse-

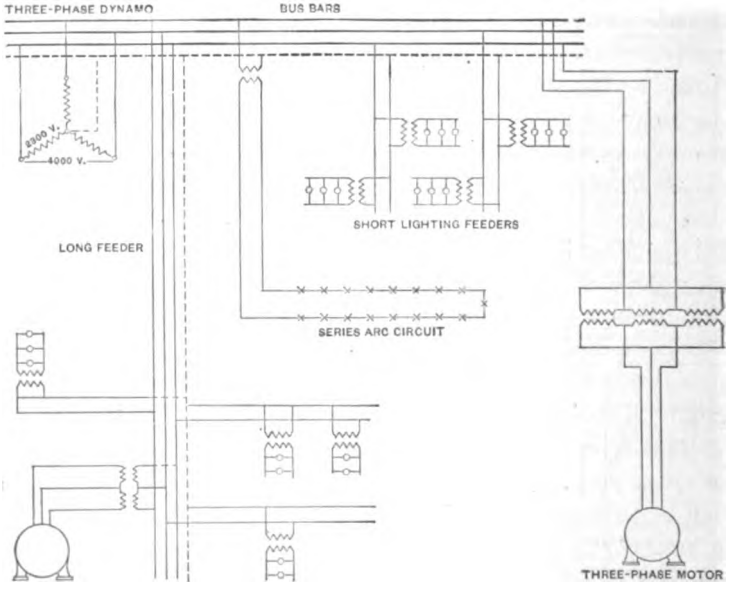

FIG. 3.—High tension four-wire three-phase system.

quently can be only partly equalized by the maintenance of a desirable average condition at the main station; even where controlling apparatus is provided in the main station the regulation may be imperfect unless considerable expense is incurred for labor necessary to the intelligent handling of such controlling mechanism. The following simple rules should always be kept in view when distribution systems are being arranged:

1st. Reduce the number of circuits to be regulated to a minimum. 2d. So arrange the system that variations not controllable from the main station are made as small as possible. 3d. Reduce the amount of total drop on all circuits so that frequent changes will not be necessary. 4th. Interconnect the load in large groups so that any variable load unit will be small in comparison to the whole of which it forms a part.

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The proper application of these rules will generally lead to an arrangement where the number of feeders is small, each feeder carrying the maximum amount of power which it is desirable to transmit over a single line. Each feeder will supply a compact primary network, or a set of short primary branches, the loss beyond the feeder end being small so that a good voltage regulation at the feeder end will ensure good service to all the customers connected to that feeder. To get such a result the load must, of course, be connected near the feeder end instead of being scattered throughout its length.

A method of primary distribution has been used and advocated to a considerable extent which frequently lends itself very well to the accomplishment of the results above mentioned. This system is illustrated by the accompanying diagram The "Y" connected generator is used with windings arranged to give about 2,300 volts between the neutral point and each outside wire. Such a generator may be loaded as if it were three separate single-phase machines, the neutral being used as a common return for all the circuits. The standard 2,300-volt transformers are adapted to use between the neutral and any of the outside conductors. The usual method of applying this system is to run out long four-wire feeders. At the end of each four-wire feeder there may be a loop or a branching of the four-wire system so that it is brought near to all parts of the area to be supplied. The transformers for lighting purposes are connected to short two-wire branches which connect to the four-wire feeder at or near its end, the arrangement of these branches being such as to give an approximately balanced load on the four-wire system. If the load is balanced thore will be no current in the neutral. Even if the unbalancing is considerable the drop in the neutral will be so small that it will only slightly affect the voltage conditions. Regulators can be used in the main stations in each of the neutral conductor, and these in combination with compensated voltmeters can maintain the desired potential at the feeder end between each of the outside conductors and the neutral. The outside conductors should preferably be grounded in the main station so that the maximum voltage to ground on any of the transformers will be 2,300 volts.

With a rough approximation to balance we virtually have, by this system three-phase transmission at 4,000 volts, the voltage between the outside wires being about 4,000 when we have 2,300

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volts between each wire and the neutral. The system thus affords means by which we can economically distribute over large areas without the use of step-up transformers.

When this system is used, it may often be desirable to operate lines in the immediate vicinity of the power station from single-phase branches, instead of running out the four-wire feeders. The neutral should simply be used as a common return where convenient, and the long lines should be so arranged that the common return will be as effective as possible. Wherever motors are used it is, of course, necessary to get access to all three of the outside conductors.

The great improvements which have recently been made in automatically regulated three-phase generators have made it economical and desirable to use such machines in many cases where direct-current apparatus would heretofore have been adopted. The alternator is simpler, more efficient and less liable to trouble than the direct-current machine, and it is often desirable to use it even where long distance transmission is not required. There are also many cases where the principal loads are found in the immediate vicinity of the installation, but where there are certain long branch lines which it is desirable to operate at high voltage. If low tension alternating current generators are used such transmission lines can always be taken care of by step-up transformers. The system recommended for such low voltage alternating distribution is the four-wire three-phase system operated from a low voltage "Y" connected alternator. The winding of the alternator is such that the voltage of lamps is provided between its neutral and its outside wires. A four-wire network is supplied from the machines through suitable feeders, the lights being operated in approximate balance between the outside wires and the neutral, and standard motors being connected to the outside wires where desired. If the standard 220-volt motors are used the desirable lamp voltage will be about 125 and with 440-volt standard motors 250-volt lamps will generally be suitable. The system of distribution with the higher voltage can be extended over considerable areas with small expense for copper, and is very desirable for mill lighting and many other purposes.

Such low voltage alternating work is desirable for railroad yards, summer hotel properties, colleges, private estates and other similar installations.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

DISTRIBUTION OF ELECTRICAL ENERGY IN LARGE CITIES.

BY LOUIS A. FERGUSON.

With the trend of modern times towards consolidation of lighting, power and transportation properties, the system of distribution of electrical energy, in large cities especially, is daily becoming a more important question, involving many perplexing problems and considerations. Were one given the problem of determining the system in an imaginary city fully developed in its business and residential portions, its growth matured and freed from the pioneering and bad engineering of the promotion days of electricity, the question would be a comparatively easy one. But as our only living ex-president has said, it is a condition and not a theory which confronts us.

Nearly every city has granted franchises to many companies having varying degrees of financial and engineering ability, so that those who are ultimately engaged in consolidating the physical properties usually find it advisable to adapt their engineering to existing conditions abandoning as little as possible of the investment made by those which they have absorbed. Not only must be considered what has been done in the past, but also the possible development of the future, so that the remodelling shall not necessarily be that which might appeal most strongly to the conditions of the moment, but of the future; for our investments, let us hope, are made not only for the present, but for the future.

The developments of the last few years have determined conclusively that the old method of installing a multiplicity of steam

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generating stations scattered throughout the city and furnishing electricity for lighting and power in the surrounding district is no longer advisable. We find the more progressive companies abandoning their smaller plants as generating stations, converting some into sub-stations and centralizing the generation of electrical energy in one or two large power stations located preferably on a water front and having direct communication with two or more railroads bringing coal from different sections of the country.

There are several instances in Europe, as well as in America, of lighting and railway companies providing for their future growth by the erection of large central power-houses of from 50,000 to 100,000 horse-power ultimate capacity. In some cases these new power-houses supplant entirely the older stations, and in others the older stations are retained intact, and are used during the peak hours of the winter months as auxiliary generating stations. This latter method is usually the more economical, since it saves a large additional investment which would have to be made for use during only a few hours daily in two or three winter months. Although the cost of generation per kilowatt hour in these old stations will be very high as compared with that of the new station, it is still wise to use them as auxiliaries to the main station or sub-station even though they be non-condensing plants, because their output being a small percentage of the total, the excess cost of their operating will be less than the interest and depreciation on the investment required in new station and sub station equipment and transmission lines to supplant them.

The choice of a site for the main power-house (water and coal facilities being equal in each case) will depend upon the combined cost of the land and the transmission of the total capacity to the sub-stations with the advantage in favor of the site nearest to the point of greatest delivered output; that is, the preference should be given to that site where the value of the land forms a larger proportion of the total than does the cost of the transmission. The less the cost of the transmission the less its length, and therefore the less cable and conduit to maintain. Since the territory to be supplied in any large city from a central power-house for general distribution of electricity for all purposes is so extensive, the adoption of a high-pressure alternating current is necessary for transmission. There may be cases in which it is possible to obtain a site sufficiently large for a prin-

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cipal station near enough to the center of greatest load to warrant the use of double current generators if direct current forms the basis for lighting and power distribution, and the energy supplied for railway purposes is relatively small. In any new principal station the generators should be of the same frequency even if it is advisable owing to local conditions that one or more be double current machines. It is always conducive to economy,

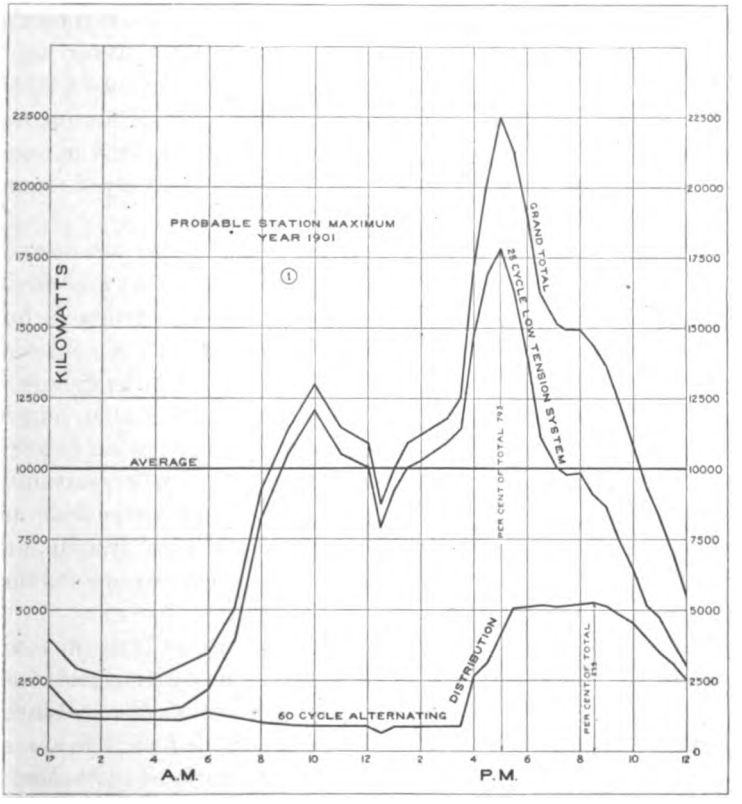

FIG. 1.

flexibility of operation and minimum initial investment that all the generators be arranged for parallel operation. The installation of both 60 and 25-cycle generators in the same station in a large city should be avoided, as the greatest economy is only possible in a station generating by one class of apparatus.

The determination of the class of current we shall generate depends entirely on the class of current we distribute. Consid-

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ering the question for a large city from the broadest standpoint, and judging by experience with the advantages and limitations of both forms of distribution, I would recommend direct current for the lighting and power work of the strictly business and city residential districts, and alternating current for the less closely built residential districts with their local business incident thereto, as well as for the actual suburban territory of the city.

An analysis of the lighting and power output (not including railways) of Chicago central station companies where this method of distribution is followed may be interesting. Referring to Fig. 1, it will be seen that of a total maximum output of 22,500 K. W., 23.4 per cent. is by 60-cycle alternating distribution over a territory of approximately 58 square miles, and 79.5 per cent. is by direct current distribution over a territory of only ten square miles.

The output shown in Fig. 1 as 25-cycle low tension distribution is largely generated at present by direct current and double current machines, as the principal generating station is only three-fifths of a mile from the largest sub-station. A considerable portion of this output will probably continue to be generated by the present low tension direct current and double current machines, even after a large 25-cycle alternating station is put in operation; but this curve is presented to show what portion of the entire load would be supplied by 25-cycle alternators and rotary converter sub-stations, if an entirely new system were being constructed, the condition toward which we are developing.

The growth of the business of the company (except in the Southern District, where a modern 60-cycle station operates) is being provided for by 25-cycle rotary sub-stations and all direct current generating apparatus will be superseded as it wears out or becomes obsolete, by 25-cycle rotary sub-station distribution in one low tension district. As the outlying residence districts become more general consumers of electricity, they are changed over to low tension direct current, and all new development in the Northern and Western Districts is supplied by motor generator sets receiving 15-cycle current from the main generating station and delivering 60-cycle current to the distribution lines.

Reference to Fig. 2 will show how the maximum load of the low tension direct current distribution was provided for last winter. It will be noticed that the rotary converter output formed

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a very small portion of the total, but in this winter's maximum we expect to turn out about three times the amount of rotary output, while the direct current delivered to the distribution mains directly from the continuous current generators will show only a slight increase. The storage battery discharge will show about 100 per cent. increase. The growth in the rotary and battery

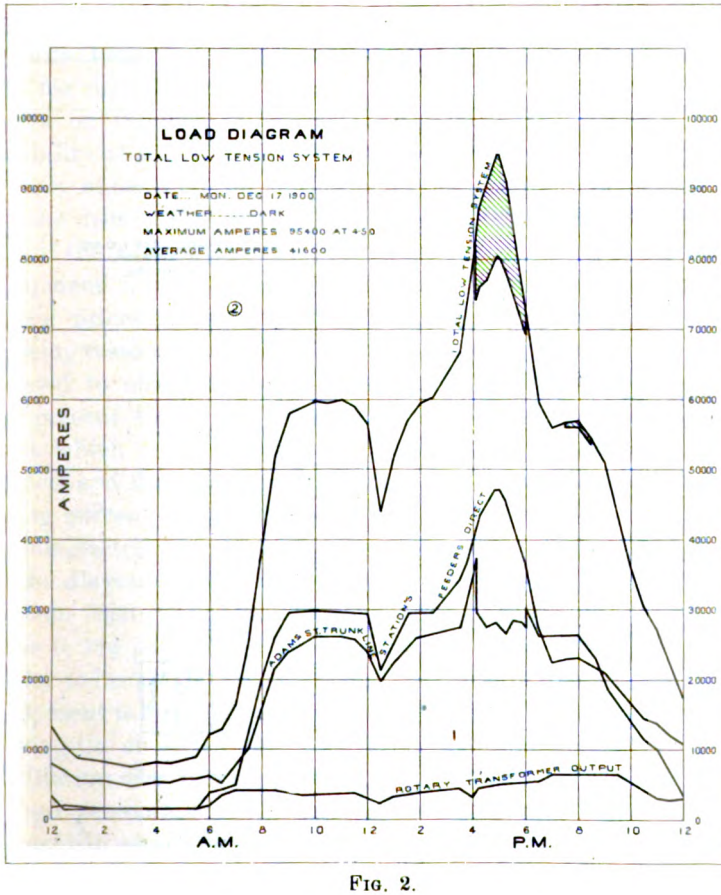

FIG. 2.

outputs and the practical standstill in direct current generating output gives some conception of how we are working towards the idea of 25-cycle alternating supply from one large station to a number of combination rotary and battery sub-stations. To effect a change of this kind without sacrificing the value and use of our present investment in direct current generating stations will take several years.

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In determining what shall be the general system of distribution, a study of the present conditions and future possibilities of electrical consumption must first be made, and the system chosen should be one that will best suit these conditions. Fig. 3 shows the relative quantities of light and power consumed monthly by the customers of the two Chicago companies. These curves represent only the actual power business for elevators and small factory use, and other general power for a large number of relatively small consumers, and do not include any street or elevated railway

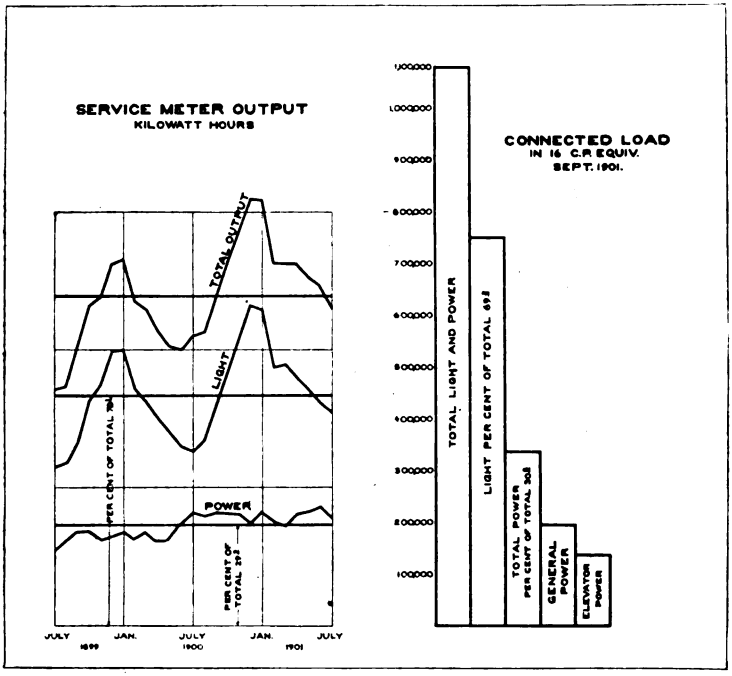

FIG. 3.

work whatever. It should be remembered, however, that any system of generating or supply which does not take into consideration this factor is not comprehensive enough to provide for the future conditions of our American cities, which will undoubtedly involve the supplying of electrical energy for lighting, general power and local transportation work from one or more large generating plants.

With the percentage of power as high as 30 per cent. (shown in Fig. 3), even when general power only is included, the great

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importance of selecting a system of generation and distribution, which is well adapted for power as well as lighting supply, will be thoroughly appreciated. It is also important to note that the power curve shows no month of the year higher than another, as the light does, and also that a daily power curve shows practically a straight line from 8 A. M. to 6 P. M. every business day of the year, while the light load shows a sharp peak of only from one to two hours' width every winter day. The importance of the power business leads us then to adopt the three-wire direct current system for distribution in the business and city residential sections shown on the map of the city as the "Central District." The feasibility of applying the direct current motor to general power work is much superior to that of the alternating current motor, and the distributing effects on line pressures are less. The initial cost of the direct current motors themselves and their attendant equipment is very much less; in fact, at the present time the selling prices of three-phase motors in America are far in excess of being reasonable. The direct current is also very much better adapted to electric elevator work than is alternating current; at the present time there is no alternating current elevator equipment which could be considered fitted for first-class high duty service, and the progress in development of an economical alternating current elevator for any service is slow. The importance of the electric elevator to the central station company is shown by the diagrammatical representation of outputs. There it will be seen that the consumption of electrical energy by elevators alone is 12½ per cent. of the total output of the companies. Our ability to install an economical and successfully operating elevator equipment is frequently the deciding feature in the question involving the choice of central station service in preference to the installation of a private plant, and with its aid we are enabled in a large percentage of instances to show to the owners of large mercantile establishments and other buildings a decided saving by purchasing electrical service from the central station company for lighting, elevator and general power service when compared with the cost of operating an isolated plant using hydraulic elevators.

The development of the automobile and its extended use in the large cities has rendered necessary the installation of charging equipments at convenient points throughout the city. With direct current the problem of charging is simplicity itself, requiring

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merely an outlet in one's stable or in the sidewalk or a charging post on the street corner. Where only alternating mains are found the installation of a charging equipment is not only very expensive in its first cost, requiring transformers, motor generator and suitable housing, but also expensive to operate, requiring a competent attendant to start and stop the apparatus; so that the net revenue to the central station company will at best be small, and often times the results of the operation will represent an actual loss.

The use of alternating current in the distribution system prohibits the use of storage batteries. Even assuming that storage batteries do not improve the economy of operating, still they are desirable wherever the service of the central station company is important. They may be adapted for use in various ways; in the central station itself when it is located at the electrical center; at the center of distribution for discharging during the peak; as auxiliaries in the rotary converter sub-stations for discharge use at the time of maximum load in the main central station, or at any time of break down of the transmission line feeding the sub-station. They may also be used in sub-stations in special districts where the load factor of the district is small, or midway between rotary sub-stations for purposes of regulation.

The greatest value of the storage battery, however, is its ability to carry us through an emergency which comes as a rule in an electric lighting or power plant with very little warning. The fully charged battery kept constantly floating on the system becomes the watchdog of the company's service, responding to a call automatically, keeping the pressure chart perfect despite blown out cylinder heads in the central station or failures in sub-station transmission lines.

The storage battery has a very distinct value, which is seldom recognized and employed to its full advantage, when located at the central distributing point of a system with feeders radiating to various points in the network. The battery may be provided with two or more end cell switches, so arranged that they may be connected in multiple and feed into the main distributing bus, or they may connect to one or more auxiliary bus bars with a different number of cells in series, feeding into each bus and thus providing two or more potentials at the center of distribution. It will be found that when only one pressure is maintained at the

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center of distribution during the time of maximum load of a large district the pressure at the ends of the short feeders will be somewhat higher than the standard and they will be overloaded, and at the end of the long feeders the pressure will be lower and the

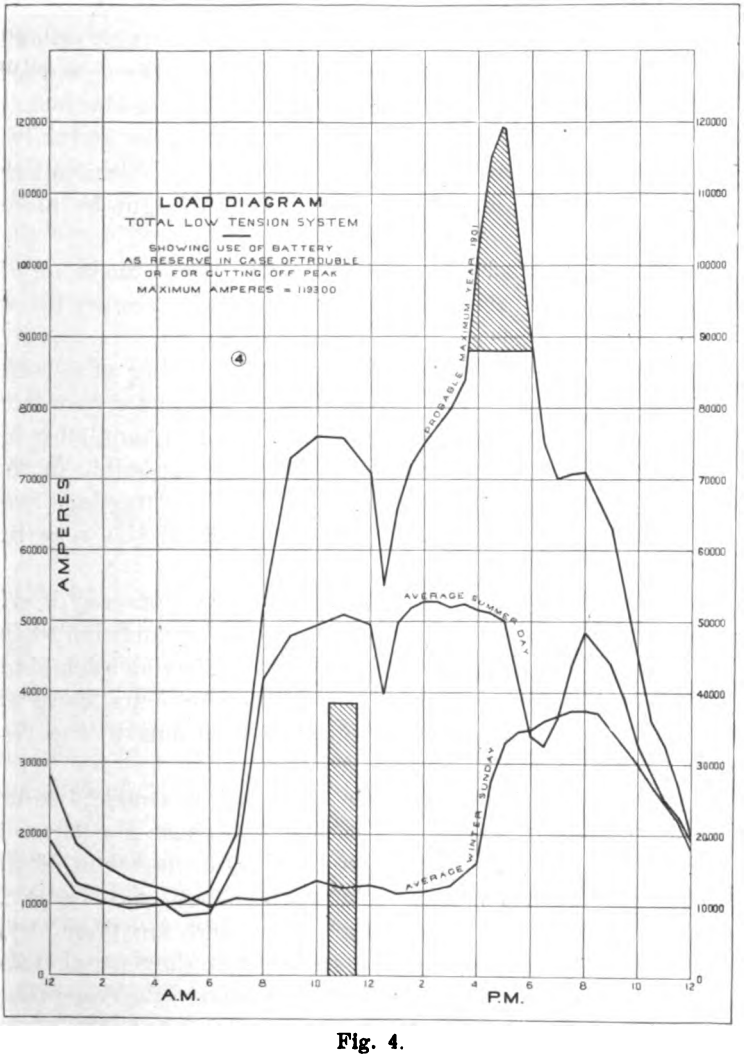

Fig. 4.

feeders underloaded, although the pressure variation at other times may be negligible. Under such conditions the storage battery becomes exceedingly valuable, for by arranging it to operate at two or more potentials, the long feeders may be connected

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during the time of maximum load to the auxiliary bus or busses and additional current forced over them, utilizing their full capacity and maintaining a uniform feeder end pressure by means of an investment in end cells very slight as compared with the investment in additional feeders and mains to accomplish the same result.

Fig. 4 shows three curves, representing two extremes of daily output, one being the Sunday curve and the other the yearly maximum curve, and also a third curve, representing the form of the company's curve for about two-thirds of the year.

The rectangular crosshatched portion shows the capacity of the batteries at the one hour rate of discharge and might be placed anywhere on the curve.

The upper crosshatched portion shows the use of the battery in cutting off the peak, thus saving an otherwise necessary investment in generating plant.

Occasions have arisen where through the bursting of a boiler tube the storage battery has saved the direct current system from shut down by carrying the entire load for about an hour, allowing time for cutting out the disabled boiler. It is impossible in this curve to show the value of the battery in maintaining even pressure throughout the system, but it is one of the very important uses of the battery.

The battery capacity of the Chicago Edison company is distributed over the entire low tension district. In addition to the three batteries in the Adams street sub-station, having a combined capacity at the eight-hour rate of 66,000 ampere hours, there are smaller batteries in three of the rotary sub-stations in the residence districts.

These batteries in the residence districts, of course, cannot economically cut off a residence load peak, because the latter is about four hours wide, but by discharging at the time of the down-town peak, which is only between one and two hours in width, they are able to cut down the demand for three-phase current at the generating station. In this way they are as valuable on peak work as though they were located in the down-town district, except that they do not save any investment in transmission line or sub-station apparatus.

Fig. 5 shows clearly the value of the storage battery in a motor generator sub-station operating an interurban railway. Its main function here is as a regulating battery used to take up the

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fluctuations of the railway and keep a nearly constant load on the motor generators.

Having determined that direct-current distribution is the most desirable for the central district of the city, and having shown that of the total maximum output of the lighting companies of the city, 79.5 per cent. is by direct current even when the promising sections of the whole city are well covered by mains, it then becomes natural to choose a system of generation for the principal stations that is best adapted to the direct current distribution, as it represents such a large percentage of the total output. We, therefore, originally adopted in Chicago for trans-

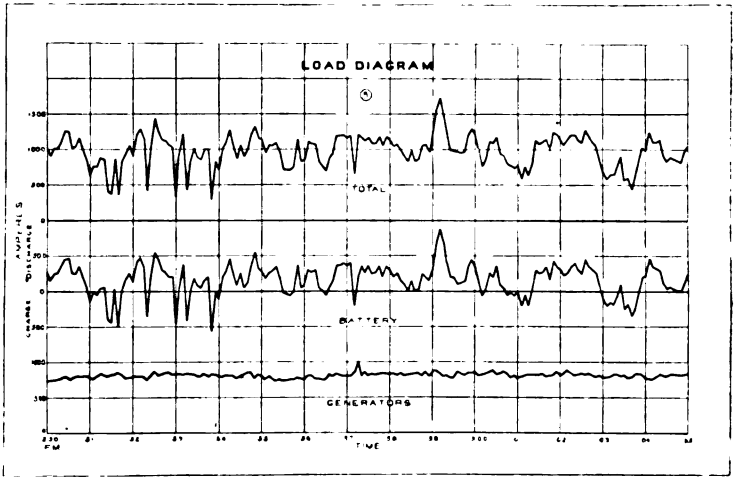

FIG. 5.

mitting to rotary converter sub-stations 25-cycle three-phase alternating current generated by double current machines at 160 volts alternating arranged for stepping up to 4,500 and 9,000 volts. The reason for employing double-current generators in preference to three-phase alternators generating the line voltage was because the principal station of the company was only three-fifths of a mile from the point of greatest direct-current output. The double current machine, therefore, could be worked at best efficiency supplying the necessary three-phase current for the outlying rotary sub-stations, the balance of capacity in the generators being used to feed directly into the low tension network thus working the generators at all times at full load.

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There has just been started in operation in this station the largest double current machine which has yet been built. It has a nominal capacity of 2,500 K. W., with overload limit for peak work to 3,200 K. W., generating 300 volts direct current and 180 volts three-phase alternating. This machine is to run in parallel with the other double-current and direct-current machines in the station as well as in parallel with a new 3,500 K. W. three-phase alternator being erected beside it to generate 9,000 volts.

As we have reached the limit of available space in our principal plants for the central district it is probable that all additional generating plants will be by 25-cycle three-phase alternators generating directly 9,000 volts, the transmission line voltage.

It is almost universally conceded that 25-cycles is the most desirable frequency for transmission and conversion by rotary converters. Sixty-cycle rotaries are considerably more expensive and much less satisfactory in their operation for the ordinary three wire network, and still less satisfactory for 500-volt direct current supply for surface or elevated railway service. Also for high voltage underground transmission the lower frequency is preferable, inasmuch as the energy loss in transmission is less and its resultant strain on underground cable insulation, whenever there is a slight disturbance on the system, is less troublesome. The kilowatt hour efficiency of transmission and transformation between three-phase generators and rotary direct-current output for the entire sub-station system equals 82.2 per cent. The portions of the city of Chicago in which 60-cycle alternating current is employed in the distribution system are shown on the map as Northern, Western and Southern districts. These territories were, when acquired, partially covered by single-phase 1,000-volt 125-cycle circuits. [See Fig. 6.]

For all these districts a four wire three-phase system from "Y" wound armatures supplied with the fourth terminal is used, the generator delivering a maximum of 4,150 volts, with 2,400 volts between the neutral point and any one of the outside terminals. There is thus available a voltage best suited for the single-phase lines in the immediate locality and the higher voltage for four wire three-phase transmission to centers in more distant localities.

In the Northern District there have been installed in the original generating station shown on the map, motor generator sets,

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FIG. 6. Scale 1 inch = 1 mile.

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the motor sides of which are fed by 25-cycle three-phase current at 9,000 volts from the principal generating station at Harrison street, the generating side of the set being a three-phase "Y" wound machine delivering 4,150 volts across its outsides, and 2,400 volts between the neutral and any outside terminal. It is the intention of the company to ultimately shut down the steam generating plant in this district and supply all the energy by motor generator sets similar to those now in operation.

Several years ago an extension was made from the Northern District power station to Edgewater, a suburb lying four miles north of this station, for the purpose of taking over the business in Edgewater, which was then supplied by a three-wire direct current local plan. The conversion was accomplished by installing in the small generating station at Edgewater two large transformers with three-wire secondaries, which were connected directly to the bus bars of the station after shutting down the direct current generators. The primaries of these transformers were fed by a 5,000-volt line from the Northern District station, customers in Edgewater then receiving alternating current over three-wire network with results which have been more satisfactory than when the local plant was operated. The regulation of the line is effected by means of induction regulators in the Northern District station.

In the Western District, where the four-wire three-phase system is likewise employed, the sub-station is located as shown on the map, and current is furnished to the circuits emanating from this sub-station by means of motor generator sets, the motor sides of which receive three-phase current at 9,000 volts from the principal generating station at Harrison street.

In the Southern District there has been erected a principal generating station, the location of which is shown on the map as Fifty-sixth street, and the territory supplied is 35 square miles. This station supplanted six generating stations formerly operated by as many different companies. The system now employed in this district is also a four-wire three phase system, single-phase mains provided with potential regulators being used for distribution in the Englewood district, which territory adjoins this station. Four-wire three-phase lines transmit at present about one-half the output of the generating station 3½ miles to Hyde Park, where a distributing sub-station is established. The first story of the building is the sub-station proper, while the second story is fitted up as an apartment for the man in charge of the sub-station. On

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the first floor there is also an office and store-room, where lamps and small operating supplies are kept on hand, the trouble man for Hyde Park reporting at this station.

The sub-station proper consists merely of a switchboard and potential regulators, which are installed on each circuit, no step-down transformers being necessary. Each circuit is equipped with a single-pole three-throw oil-balancing switch, by which the single phase circuits are balanced on the three-phase bus bars. From Fifty-sixth street station a transmission line also runs 8¼ miles to South Chicago, where another local center for distribution is established.

The system of distribution in these outlying districts is such that series alternating arc lights may be operated when desired from the bus-bars of the generating station or sub-station.

The method of generating low frequency alternating current in one or two large stations and transmitting the energy at high voltage to sub-stations for conversion to direct current in thickly settled districts is now being adopted in some of the large and more progressive cities of Europe, notably in Berlin and Milan.

The general scheme of generation and distribution in Berlin is similar to the system in use in the central district of Chicago, with the exception that in Berlin, motor generators are used instead of rotary converters. Their practice also differs from the American in that the direct current network is not interconnected, as for some reason they consider it dangerous to do so.

In addition to the former direct-current stations in the central district of Berlin, they have erected two large stations away from the center of the city, each having an ultimate capacity of about 40,000 horse-power. In these plants three-phase current is generated at 6,000 volts by direct coupled three-phase units, and is transmitted to the various sub-stations throughout the city. One of these sub-stations has at present a capacity of 7,000 k. w., current being taken in at 6,000 volts and reduced by means of three part transformers of 1,000 k. w. each to the proper working pressure for operating motor generators of about the same capacity. The generating side of each is wound for 250 volts. It is the practice of the Berlin company to use storage batteries in connection with sub-stations in much the same manner as is being done in American sub-stations.

The general scheme of transmission and distribution in the City of Milan involves the use of three-wire direct-current distri-

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bution in the central portion of the city, supplied by a motor generator station located near the Cathedral, with a 3,600 volt three-phase primary distribution for the territory beyond the central district. Current is generated at 13,500 volts with a frequency of 42 cycles per second by three-phase alternators in the water-power plant located at Paderno, 32 kilometres from the steam station at Porto Volta. At the latter point the voltage is reduced to 3,600 volts by step-down transformers and connections made in parallel with the 3,600-volt generators in the steam station at Porta Volta. From this 3,600-volt bus, current is distributed throughout the outlying portions of the city by means of primary mains which feed transformer houses located at convenient points. From these transformer houses small secondary networks are built to supply the customers in the neighborhood.

The sub station near the Cathedral receives its current at 3,600 volts from the main bus bar in the station at Porta Volta, the motor side of the generators in the sub-station being wound for 3,600 volts.

The Milan Edison Company operates the street cars of the City of Milan as well as doing the lighting and power work for the city, the motor generators in the sub-stations being also used for operating the street cars.

Storage batteries are used in Milan for both railway and lighting business, the railway battery having a capacity to take care of the maximum load of the railway for one hour, and the lighting batteries being sufficient to take care of the full direct current lighting load at the time of peak.

The general principles and systems which have been here advocated as advisable for Chicago should be applicable to any large American city as the general conditions in all large cities are approximately the same. This, however, may not necessarily be true in the case of the smaller city or town as they are usually affected by some local conditions, and in some instances even the general conditions may not be such as to make the same system applicable.

The aim of every central station manager should be to strive for simplicity and interchangeability in his system of generation and distribution, avoiding as far as possible multiplicity and complexity of methods, building up a distribution system which shall be universal, thus standardizing the customers' appliances and apparatus throughout the city.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

LOCATING FAULTS IN UNDERGROUND DISTRIBUTION SYSTEMS.

BY HENRY G. STOTT.

With the rapid and extensive growth of underground cable systems for the distribution of electricity for light and power purposes a problem of great practical importance has arisen, namely, to find a method of quickly and accurately locating a fault or ground in any part of the system.

With small conductors, such as those used for telegraph cable, the ordinary Blavier and loop tests with galvanometer, Wheatstone bridge and battery suffice; but the percentage of error in locating a fault varies directly with the cross-section of the conductor or inversely as the resistance. Any one familiar with the most refined methods of battery test will admit that the loop test is the best of all, as it eliminates the worst variable, namely, the fault resistance. Even under the best conditions the loop test has an element of uncertainty in the variation of the zero on the galvanometer due to earth currents getting into the cable through the fault. In a city, the source of this error becomes of greater importance than in submarine cables, owing to the leakage of street railroad currents through the earth from the rails. As a matter of fact, it is frequently impossible to use a sensitive galvanometer on any test involving the use of the earth as a part of the circuit.

Loop tests carried out with the comparatively large current of ten amperes, using millivoltmeters instead of reflecting galvanometers in the hope that the stray currents would thus become such a small percentage of the test current that the

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errors due to the presence of the former would be practically eliminated, also failed entirely, and the conclusion was reluctantly reached that the galvanometer and battery must be abandoned whenever the resistance to be determined was less than .25 ohm.

The distance between manholes is evidently the practical degree of accuracy essential to any successful method. This will average about 350 feet. Assuming that .25 ohm is the limit of accuracy obtainable under these conditions, in the loop test this means that the method is not applicable to any conductor larger than No. 9 B. & S. gauge, and therefore of no practical value for lighting and power purposes.

Resistance measurements having been eliminated as a possible means of solution, there remain three others, which may be called :

(*a.*) "The cut-and-try method."
(*b.*) "The smoke method."
(*c.*) "The compass method."

(*a.*) The "cut-and-try method" is too well known and too bad to merit much description, as it simply means cutting the cable into as many sections as necessary until the fault is finally located in a length between manholes. This is a slow, expensive and unscientific method, and should only be used as a last resort. A three-conductor high-tension cable joint costs from five to ten dollars, and a jointer and helper cannot make more than two per day, so that if the cable is five or six miles long it may easily take four or five days to get the cable in service after removal of a fault.

(*b.*) The "smoke method" is also crude, and simply consists of putting a current of sufficient magnitude into the cable through the fault, to cause the insulation to burn and give out volumes of smoke, by means of which the location of the burnt section may be discovered upon opening up the manholes.

The method is more rapid in yielding results than (*a*), as no unnecessary cuts are made in the cable, but it may give rise to serious trouble in other cables, especially if the fault be in or near a manhole, as the flames may burn not only a great length of the cable itself, but also other cables, or cause explosions due to the ignition of the gases ever present in all city conduits.

(*c.*) The "compass method" is, in the writer's opinion, the only practical and safe means of quickly and accurately locating a

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ground in cables larger than No. 9 B. & S. gauge. This method consists, briefly, in sending a constant continuous current of about 10 amperes into the cable through the ground, the current first passing into an automatic reverser which reverses the direction of the current flow every 10 seconds. A manhole is then opened near the center of the cable length and a pocket compass laid on the lead sheathing of the faulty cable and observed for say half a minute. If the ground is further from the source of reversed current the compass needle will swing around approximately 180° upon every reversal at the end of each 10 seconds interval. The manhole is immediately closed and another opened, say a mile further away from the source of test current, and if no motion of the compass needle occurs. then the fault has been passed and another manhole is opened between the two first positions, and so on until the fault is finally located in a section between two manholes.

It will be observed that by this method (1st) the cable is not cut, thus causing no delay or expense in rejointing; (2d) the number of manholes opened is a minimum, and the time spent in each is only about one minute; (3d) the amount of current used is so small that no arcing or burning occurs and no explosions.

Figure 1 shows one form of reverser used by the Manhattan Railway Company, consisting of a ¼ H. P. three-phase induction motor, geared to a two-part commutator, which revolves in oil in order to ensure the quick reversal of current without danger of arcing across between segments. An ordinary constant continuous current arc light machine is the most convenient source of current for this test, as it will supply a constant current throughout a wide range of voltage, thus automatically adjusting itself to the varying fault resistance. Should an arc light machine not be at hand 500-volt current can be used through a resistance and reverser.

Before putting on the reversed current it is advisable to break down the fault resistance by the application of a high potential testing transformer to the cable for a few seconds.

This method of test is especially useful in any network of cables, such as 2,200 volt single, two or three-phase mains, and feeders, as the test current can be run on the network, without shutting down the supply service or interfering with it in any way, by simply sending the 10-ampere reversed current through

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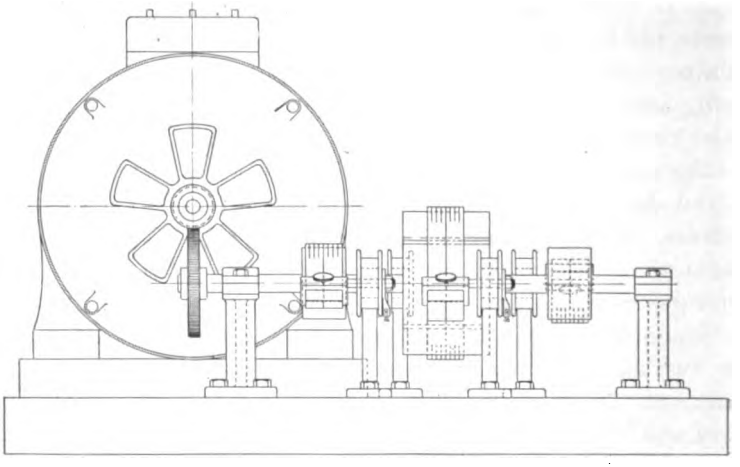

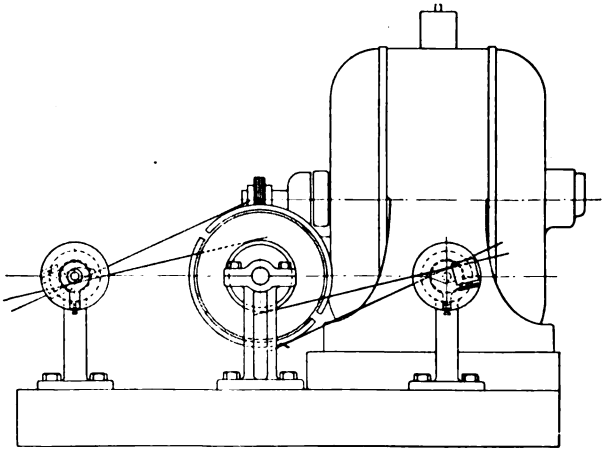

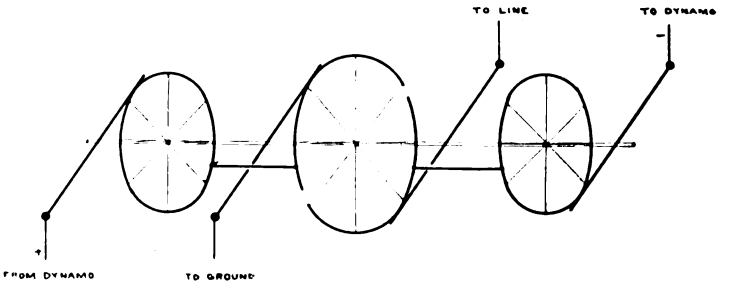

DIAGRAM OF CONNECTIONS

Fig. 1.—Motor Driven Current Reverser.

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a reactive coil (or the primary of a transformer) before entering the grounded main. This is merely done to protect the arc light generator in case another ground should develop and thus cause a short-circuit on the A. C. generator. This method of testing live circuits is only applicable, of course, to those supplying alternating current and having no permanent ground attached.

After using this method of locating faults for four years, the writer cannot recall any case, in which the method was properly applied, that required more than three hours to locate a fault in cables having a length of from four to six miles. The whole secret of this rapidity lies in the fact that the first test at the center of the line eliminates one-half of the cable from the question. To find a fault in a duct between manholes in a similar length of cable, by any other method known to the writer, may easily take two days, and as many more may be required to repair the cuts.

The writer trusts that the above notes may be of some practical value to the profession, and that the method recommended will be found as certain and satisfactory by those who have not as yet used it as by those who have.

New York, November 8, 1901.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

THE BUFFALO HIGH-TENSION CABLE DISTRIBUTION SYSTEM.

BY HAROLD W. BUCK.

In the development of the electrical transmission of power many propositions are being presented of a water power or coal mine situated within such a distance of a city that it is cheaper to transmit power from the mine or waterfall than to generate it by steam in the city itself. In such systems three engineering elements must be considered: first, the generating plant; second, the transmission line, and third, the method for distributing the power at the end of the transmission line. Electrical generating plants and transmission lines have been the subject of many discussions, but the terminal arrangements for transmission lines are newer in their development, and it is the object of this paper to bring the matter up before the members of the INSTITUTE for discussion, the problem presented being the best method of distributing the power throughout a city after a point has been reached on the transmission line where it is no longer safe to carry the power overhead at the transmission voltage. Such limitations exist on the outskirts of all cities.

In order to serve as a basis for discussion and to point out the various considerations which enter a brief description will be given of the method which has been adopted for the distribution of Niagara power in Buffalo.

Fig. 1 shows a map of the Niagara-Buffalo transmission line indicating the relations between the overhead circuit and the circuits of distribution within the Buffalo city limits, the numeral 3 on the map indicating the terminus of the 22,000-volt overhead

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three-phase lines. At this point the three overhead circuits, each having a capacity of 10,000 H. P. at 7 per cent. line loss, enter a terminal house, and are connected, as shown in Fig. 2, through circuit breakers, selector switches, bus bars, etc., to the 22,000-volt primaries of the step-down transformers. These transformers have a capacity of 3,000 H. P. each, and are of the oil-water cooled type. The secondaries of the transformers are wound for 11,000 volts, making the ratio of reduction of voltage 2 : 1. The secondaries of the transformers are connected through selector switches and two sets of bus bars to the underground cables, each of which is connected through an air-break circuit-breaker. With the arrangement shown, the Buffalo system can be operated in two sections if desired, and any overhead circuit or any cable con-

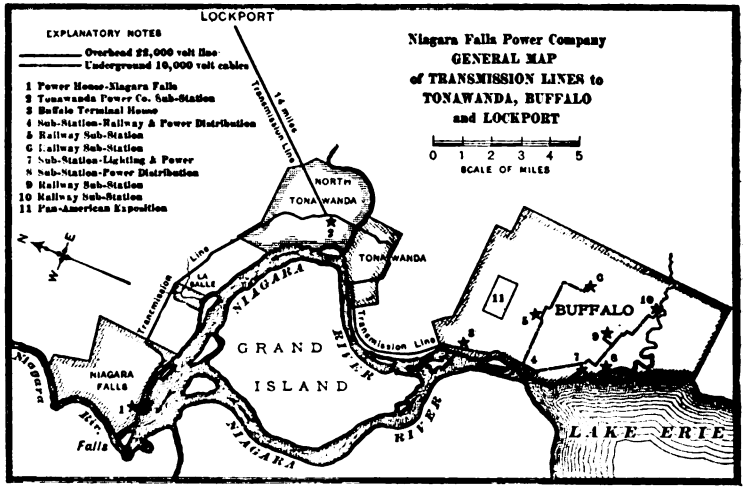

FIG. 1.

nected to either of the banks of transformers. The 11,000-volt cables supplied from the secondaries of the terminal house transformers are drawn through tile ducts under the streets in the usual manner, and carry the power to the various sub-stations throughout the city of Buffalo. At present there are five feeders, each consisting of No. 000 triple-conductor lead-covered cables. Two of these have 9/32″ rubber, two 8/32″ rubber and one $6\frac{1}{2}$/32″ paper and 4/32″ paper over-all. The lead in all cases is $\frac{1}{8}$″ thick.

Fig. 3 shows the general arrangement of cables throughout the city, with the various methods which are used for transferring

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from one to another and for cutting out damaged sections of a cable by means of section switches, so that the entire length of cable from the terminal house will not have to be cut out of service. Special attention is called to these section switches, which are shown in Fig. 4. They are of the triple-pole, single-throw type of oil-break switch, with a waterproof hood of iron bolted to the top of the switch frame for the protection of cable heads and leads. These switches are installed in vaults under the city streets, placed at convenient intervals. Some of the vaults are as large as 10′ x 12′. The switches are absolutely waterproof

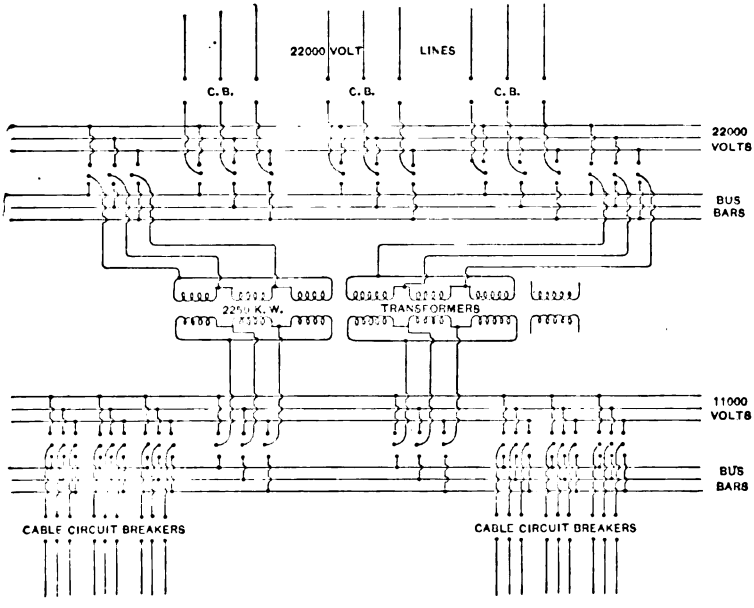

FIG. 2.—Connections Buffalo Terminal House.

and could be submerged, if necessary, without danger, and will open the circuits under heavy loads without difficulty. They have proved of great convenience at times when repairs have been necessary on sections of the cables, and for locating faults without the necessity of cutting the cable. I believe that underground section switches of this kind would prove of great service to all high-tension cable systems, and believe that the design shown is entirely safe for service at 11,000 volts.

In all, seven sub-stations are supplied with power at 11,000 volts, three-phase, distributed as follows with reference to Fig. 3 :

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Station No. 4.—2,000 H. P. for railway purposes, transformed from 11,000 volts to 360 volts, and fed to four 500 H. P. rotary converters. 1,000 H. P. for general power distribution on a tertiary system at 2,200 volts, three-phase, the voltage being lowered from 11,000 volts, by three 250 K. W. transformers. This 2,200-volt distribution is partly overhead and partly underground.

Station No. 5.—1,500 H. P. for railway purposes, transformed from 11,000 volts to 360 volts, and fed to three 500 H. P. rotary converters.

Station No. 6.—1,000 H. P. for railway service, as in Station No. 5.

Station No. 7.—5,000 H.P. is transformed from 11,000 volts to 360 volts and fed to the plant of the Buffalo lighting company in an adjacent building. 1,000 H. P. transformed to 2,200 volts, three-phase, for general power distribution on the tertiary system.

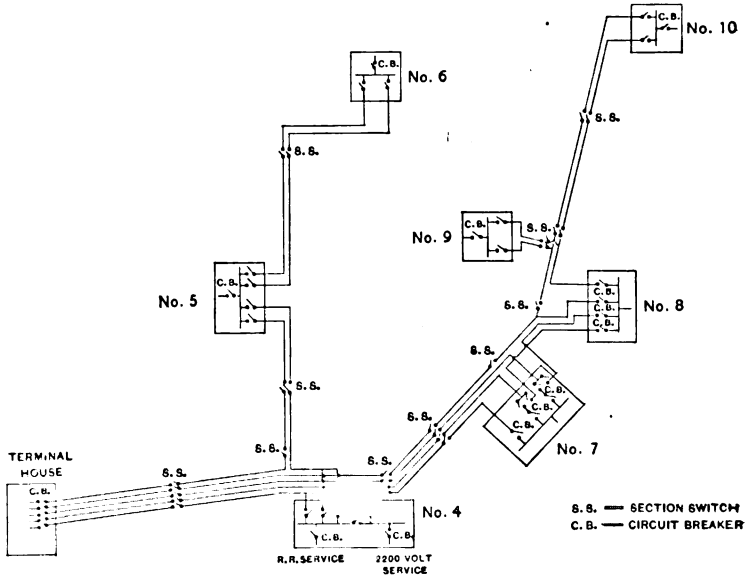

FIG. 3.—Buffalo 11,000-Volt Cable System.

Station No. 8.—2,000 H. P. transformed from 11,000 volts to 2,200 volts three-phase, for power distribution on the tertiary system.

Station No. 9.—1,500 H. P. transformed from 11,000 volts to 360 volts, for supplying power to three 500 H. P. rotary converters for railway purposes.

Station No. 10.—1,000 H. P. for railway purposes, as in Station No. 9.

It might be asked why the power is not transmitted from Niagara Falls at 11,000 volts and distributed through the underground cables without transformation. It will be found, however, that the saving in copper on the transmission lines by the use of 22,000 volts more than pays for the transformer installa-

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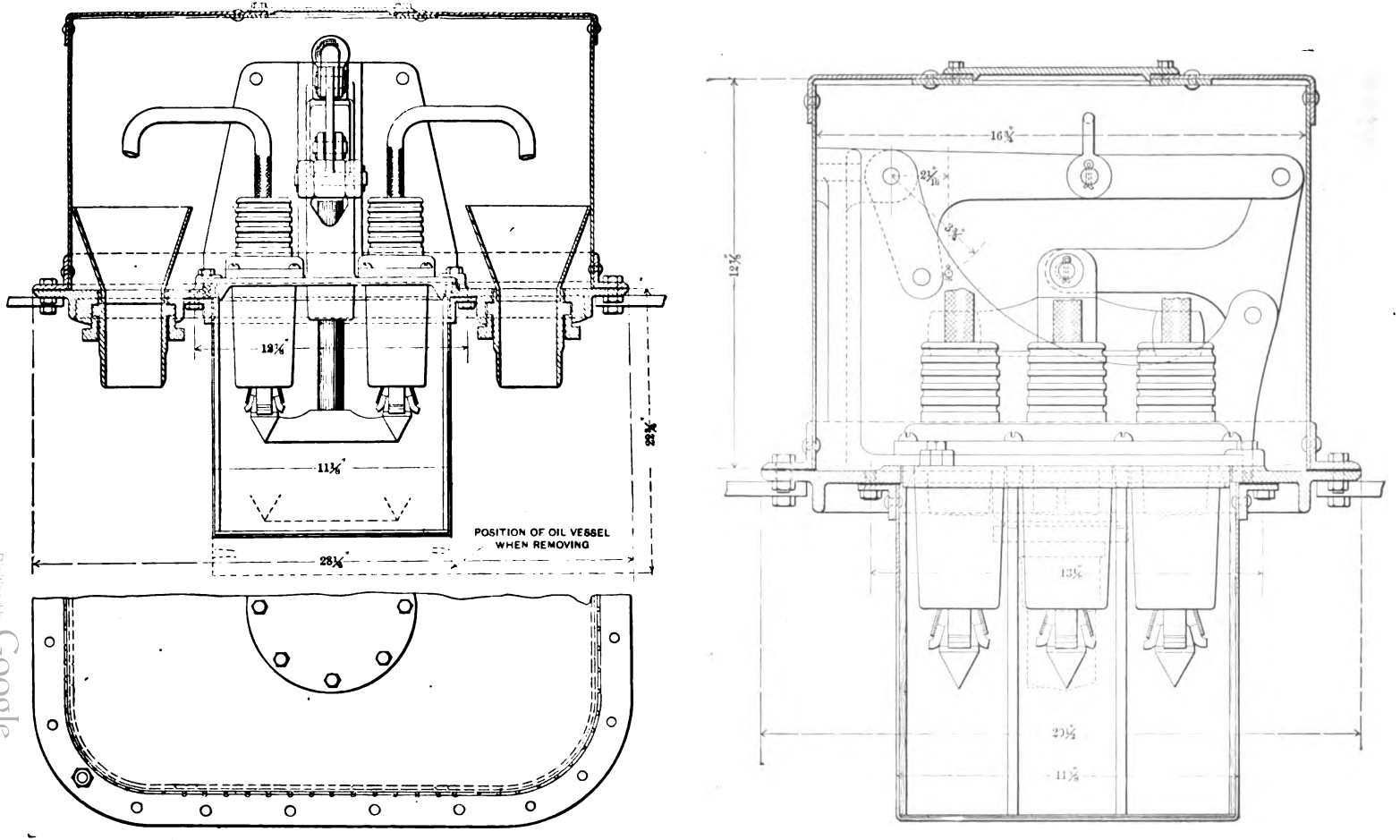

Fig. 4.—Underground Switch.

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tion in the terminal house, and that the saving in line loss is greater than the loss introduced by the step-down transformers. The longer the transmission line the greater would be the proportionate saving. It may also be asked why, if the overhead lines are to be operated at 22,000 volts, the transmission cannot continue at this voltage throughout the cable system in order to avoid the use of step down transformers. It is true that there have been examples of successful operation of underground cables at voltages even higher than 22,000 volts, notably the transmission from the plant of the St. Croix Power Company; but, obviously, what can be done on a through trunk line cannot be safely done on a network, and the Buffalo underground system is essentially a network. It has many lateral connections, frequent joints, section switches, cable heads and switchboard connections, and under these conditions, which are probably no different from the requirements of other cities, I believe that 11,000 volts is, in the present state of the art at least, the highest voltage which should be considered. The success of the Buffalo power distribution at 11,000 volts, which has covered a period of about four years, has, however, demonstrated the safety and feasibility of using a potential as high as this, provided the greatest precautions are taken in the selection and installation of cables, and in the insulation of all terminal appliances. It seems to show that there is no longer any reason for fixing the prevailing voltage of 6,600 volts as the safe limit for underground work and for paying for the extra copper and ducts required by the lower voltage.

In cases of short-circuit in the cables, practically no damage is done at 11,000 volts on account of the small current. Short-circuits have occurred on these cables, which have had the whole of Niagara power back of them, and it has been found, after locating the fault, that the lead was barely melted off around the fault. At 6,600 volts such a short-circuit would undoubtedly blow the cables to pieces on account of the greater current, the heat energy at the fault being nearly four times as great. This is a practical advantage, for it reduces the risk of damage to adjacent cables and ducts.

In the city of Buffalo, then, we find a distributing company called the Cataract Power and Conduit Company purchasing power from the Niagara Falls Power Company at the Buffalo city line, at the transmission voltage, lowering it to 11,000 volts, three-phase, 25-cycles, and distributing it as raw material in this

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form as dealers in power. To the railway company it is delivered for transformation and conversion for use on their own direct-current circuits, to the lighting company for conversion into the various forms in which they re-distribute it to small consumers, and it is also delivered to various factories using power in quantities from 75 H. P. and upwards, to which consumers power is supplied from the tertiary system mentioned at 2,200 volts, three-phase, from sub-stations owned and operated by the Cataract Power and Conduit Company.

From a business as well as an engineering standpoint it is believed that the methods used in Buffalo as described are very satisfactory and economical. The primary company, viz., the Niagara Falls Power Company, confines its attention to the generating plant and transmission line, the distributing company to the delivery of three-phase 25-cycle alternating current power, and the railway and lighting companies to the interests of their own circuits. This separation of responsibilities is entirely logical and most convenient. It would still be better if the Cataract Power and Conduit Company could confine itself to the delivery of power at a single voltage, viz., 11,000 volts, but the tertiary distributing system at 2,200 volts is necessary, for the reason that it is obviously not safe to supply small consumers of power, such as small factories, with connections, at so high a voltage. By transformation to 2,200 volts the numerous "grounds" which occur on these circuits are made independent of the main cable system, and the induction of the transformers adds to the self-introduction of these circuits and limits the violence of short-circuits which occur upon them.

The transformation of voltage at the city line from 22,000 volts to 11,000 volts, beside being necessary, is also a positive engineering advantage, for the reason that it renders the 11,000-volt cable system independent of "grounds," and high voltage disturbances from lightning, resonance, etc., which occur at times on the transmission line, since there is no electrical connection between the two. Although there have been several instances of rises of potentials on the overhead line far above the normal, resulting probably from resonance, no rises of voltage have been noted as having been transmitted to the cables by induction through the cores of the step-down transformers.

It is believed that the methods here described are practicable and convenient, and can be safely followed in principle by those who are planning similar systems of distribution.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

ALTERNATING CURRENT AS A FACTOR IN GENERAL DISTRIBUTION FOR LIGHT AND POWER.

BY CHARLES F. SCOTT.

The foregoing title immediately suggests the old-time controversy, alternating *versus* direct current. The present problem, however, may be more accurately stated, alternating current only, *versus* alternating current and direct current.

The economical radius of direct current supply from a central station is so limited that even in a strictly direct-current system, if it covers considerable area, recent engineering prescribes a large alternating current generating plant furnishing power to rotary converter sub-stations, and from these the direct current is distributed. This is witnessed in recent installations in Greater New York.

The problem, therefore, is this: For general distribution for lighting and power service where the current is generated in alternators, is it desirable to utilize the current as alternating current or convert it into direct current?

Before taking up in detail the various elements involved, the following statements may in general be considered as axiomatic:

(1) Simplicity demands a uniform system with elements as few as possible and requiring a minimum of attention. Converting apparatus requires rotating machinery and the presence of attendants, and these involve first cost, operating expense, complication and liability to interruption of service.

(2) In classes of service for which direct current possesses no advantage over alternating current, conversion is undesirable. For

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example, the simplest case is incandescent lighting. It is doubtful whether any one would propose converting to direct current if incandescent lighting alone is to be supplied.

(3) In outlying districts or other territory where the output from a sub-station would be quite small, it would obviously not be economical to convert into direct current, as many of the expenses of such a sub-station would be relatively large, so that the cost per kilowatt for converting into direct current would be excessive.

These conditions limit the general problem, and the question may now be stated thus: In those cases in which the conversion from alternating into direct current is commercially practicable, is it necessary or desirable?

It will be readily granted that usually a large part of the service would be as satisfactory if operated by alternating as by direct current. With regard, then, to those elements in which there is a difference of opinion, are the reasons for the use of direct current sufficient to justify the increased complications and expense of the converting apparatus?

To answer this intelligently, we will consider it in two divisions:

(*a*) In the utilization of electric energy, what advantages has direct current over alternating current?

(*b*) When energy is generated as alternating current, what disadvantages are involved in utilizing it as direct current?

Taking up the first of these, let us consider the ordinary classes of service and the means of providing for them.

Incandescent lighting may be considered as indifferent to the character of the current, whether it is alternating or direct, provided the frequency be sufficiently high to prevent flickering.

Arc lighting is most extensively carried on by the enclosed arc lamp, which is satisfactorily operated from direct current circuits, and also from 60 cycle alternating circuits so that there is no compelling reason for choosing either one current or the other as far as arc lamps are concerned.

The Nernst lamp, which is quite satisfactory in its operation on alternating current but not on direct current, gives a positive reason for choosing the former.

In discussing motor service it is not the intention here to enter into a controversy as to the relative merits of alternating and

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direct current motors. Suffice it to say that both are in extensive use for nearly every kind of service. The induction motor is notable in having no commutator, and on account of its ability to stand various kinds of abuse, it is especially fitted for general distribution of power in all sorts of places, as such motors receive little or no attention.

For constant speed work probably no one will question the superiority of the alternating current motor from the standpoint of the man who uses the motor and pays for repairs. Any objections which may be brought forward will probably be urged on account of reasons applying to the supply system, such as power factor, starting current and voltage regulation. These items may be provided for by properly designing the system, and they cannot be regarded as legitimate objections to the use of the alternating current motor.

For variable speed work the conditions are different; the fundamental difference is due to the fact that although there is a close correspondence between the performance of the induction motor and the direct current shunt motor, with constant field excitation the alternating current motor does not have an exact analogue to the direct current series motor. It follows that induction motors cannot exactly duplicate all direct current motors. Therefore the results which may be desired must often be obtained in a different way from the methods employed with direct current motors.

From the above summary, it appears that all of the important classes of service for which current from a central station is used may be successfully undertaken either by the direct current or by the alternating current; sometimes equally well, sometimes with the advantage on one side and sometimes with the advantage on the other side. The most important difference is probably in the case of variable speed motors and the importance of this will depend quite largely on the proportion of this kind of service. Although the alternating current motor cannot exactly replace the direct current motor, so that there may be some inconvenience in changing from one system to the other, yet when a new plant is being laid out, it is probable that the cases are very rare in which it would not on the whole be practicable to utilize either alternating current motors or direct current motors.

To consider next the apparatus employed for producing and distributing current, the elements in the two systems may be set forth as follows:

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ALTERNATING CURRENT ONLY.	ALTERNATING AND DIRECT CURRENT.
Alternators,	Alternators,
Switchboards,	Switchboards,
Primary Mains,	Primary Mains,
Transformers,	Sub-stations with Switchboards.
Distributing Circuits.	Transformers,
	Switchboards,
	Rotary Converters,
	Switchboards,
	Distributing Circuits.

Comparing these in detail, the generating station in general will be substantially the same for the two systems, although a higher frequency will usually be employed if there is little or no conversion to direct current.

The primary feeding system will also be substantially the same in the two cases, differing, however, in the number of points at which the transformation is made to the low voltage, and the distributing system is supplied with current.

The sub-stations for conversion into direct current constitute the great difference between the two systems. Sub-stations with converting apparatus are expensive to install and to operate. The cost of the sub-station naturally makes it desirable to have as few as possible; hence they are located at as great a distance apart as the distributing circuits will permit.

The cost of distributing circuits for direct current is therefore very much greater than for the low tension alternating current circuits to which current is supplied from a large number of transforming points since the alternating current circuits are comparatively short, and the cost of copper is hence greatly reduced. This effects a saving not only in the cost of the conductors themselves but also in subways and ducts, which are often limited in capacity and high in cost.

The liability to accident and interruption to service is inevitably greater in the system which converts to direct current, than in that which merely transforms to a lower voltage, since the sub-station with its switchboards and rotating machinery intervenes between the generator and the consumer.

The storage battery is an element which is sometimes presented as a reason for adopting direct current, as it may be readily added to the system. It may, however, be used in connection with alternating current distribution. A rotary converter may be employed

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for charging the storage battery, and in turn the battery can supply current through the converter to the alternating circuits. In this manner the battery may be related to the alternating system in substantially the same way that it is usually related to the direct current system, except that the converter is between the battery and the service.

The foregoing general comparison between the two generating and distributing systems evidently favors the one which employs alternating current only. The introduction of converting apparatus therefore must be justified by advantages accruing in connection with the utilization of the current, which are sufficiently great to overbalance the extra cost and complication.

To change an existing direct current system into an alternating current system is in many cases a difficult matter. The circuits which are suitable for direct current may not be suited for alternating current. The motors used for the direct current would of course be useless on the alternating circuits. These and other similar points complicate the general problem, and when an existing direct current plant is to form part of a large system, such considerations often determine the plan to be followed.

The foregoing discussion applies particularly to large city plants for supplying lights and stationary motors for general work, and it has been assumed that the entire service is supplied either by direct current or by alternating current. There are, however, some cases where a combined service is advantageous, alternating current being supplied for certain districts, and direct current for others.

In cities, a combined service for general distribution is sometimes applicable for furnishing direct current from sub-stations to districts which have previously been supplied by direct current generating plants, while alternating current is furnished to the outlying parts. The same generators may be used for both classes of service, and may supply them simultaneously. Quite similar results may be attained from a direct current generating plant, the alternating current being obtained from inverted rotary converters.

In smaller towns a combined service from an alternating current plant is often used for supplying railways by 60-cycle rotary converters in connection with general lighting and power, the latter service being entirely by alternating current. In many

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cases the lighting and railway work can be operated from the same bus bars, as the automatic compounding of the rotary converters is such as to make the voltage upon the general system sufficiently constant for lighting service.

Probably the most pertinent conclusion to be drawn from a discussion of this kind is that there is no ideal system, and no panacea plan which can be universally applied. Existing and local conditions, special requirements and the relative importance of the various classes of service to be rendered, must all be taken into account in determining what will be adequate in an individual case.

The systems which we have been discussing have an important and far-reaching influence upon industrial life and social activity aside from their engineering aspects. It would be difficult to find an agent more instrumental in bringing about the unification and concentration of diversified industries and interests than electric energy in the form of alternating current.

The recent electrical development in Greater New York demonstrates this on a magnificent scale. A generation ago it would have defied the imagination to discover any natural connection between such widely different agents as horses pulling street cars, locomotives drawing elevated trains, gas lighting houses and streets, water operating elevators, stoves heating and cooking, and engines of every sort and class doing a hundred kinds of work. But all of these and many others are in common being superseded by the electric current, which does not merely replace but develops, expands and transforms. It is notable that all of this varied service is to be supplied from alternating current generators; also that the outcome of the evolution of plans for general distribution and for railway work is identical in that alternators of the same frequency are being installed for both, so all could supply current to a common universal system.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

NOTES ON THE ALTERNATING CURRENT SYSTEM OF DISTRIBUTION.

BY W. S. BARSTOW.

Distributing systems are usually referred to under two headings—direct and alternating.

The direct current distributing system, starting in the early '80's and appearing generally in its three-wire form, is what may be termed a universal system, since from the same conductors, and without any modification whatever at the customer's service, current is furnished direct to any electrical apparatus, whether for supply of power, light or heat.

The alternating current distributing system, making its appearance in its single-phase form about the same time as the direct, never started as a means of universal supply, being confined in its earliest stages of development to the furnishing of energy for light and heat only. To the absence of the alternating current motor can probably be traced its restricted use and the early slow progress in this form of current supply. Had there been early developed a single-phase motor which would have met all the conditions of a direct current motor in construction, economy and cost, then there is no doubt but what the three-wire, single-phase alternating current system would have come rapidly to the front. As to whether it would take the place at the present time of large installations of direct current supply, might perhaps be doubtful, since the storage battery as a part of the general system is gaining ground and rapidly becoming indispensible.

The alternating current distributing system was first exploited as a house-to-house supply, and continued as such until within

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recent years, when efforts were made to interconnect the secondaries to increase the efficiency and reliability of the system. It was soon found, however, that the paralleling of transformers in old systems already erected, through small secondary mains, was much like paralleling compound generators through a small equalizing bus, and many failures were the result. Steps were then taken to install mains of such a size as to make the drop or loss between two transformers negligible, and for a short time many plants operated successfully with transformers in multiple on fairly long secondary mains. As the demand for current on the mains increased, however, the change in the size of conductors was not followed up, and the old trouble returned. The system, to-day, therefore, has almost reverted to a house-to-house supply, although the transformers are arranged in groups, connected to secondary mains, and providing, in case of accident, for interconnection.

The only practical and successful method of paralleling transformers on secondary mains of distribution is the placing of each transformer or bank of transformers on a separate feeder and providing at the station means for regulation on such feeder, so as to make it possible to divide up the load on the different transformers and compensate for any difference in transformer regulation. Such a system is in successful operation in several large plants, and is productive of good results. When the alternating current system is permanently standardized the transformer will no doubt be considered a part of the feeder, only one transformer or bank of transformers being installed at a single distributing point of a single feeder.

As before mentioned, owing to the early absence of any commercial single-phase motor, there was no incentive to standardize and develop the alternating system, as has been done in the case of the direct, and it was not until the last few years that the alternating system, by the abandonment of the single-phase and the change to multiphase, approached anything like a universal system of supply. Up to the time of the appearance of the multiphase motor the development of motor business on alternating systems was very restricted, as the uses to which the single-phase motor could be put were more or less limited. On the other hand, the introduction of the multiphase motor necessitated a change in the entire system of distribution, and it is not until the last few years that single-phase has entirely given place to

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multiphase systems; not, in fact, until it became apparent that the multiphase motor, under any stage of development, would prove superior to the single-phase. Probably the simplest multiphase alternating current distributing system which would be first thought of would be the two-phase, three-wire primary and three-wire secondary. Such a system might be satisfactory where light only is used and where the middle wire of the secondary system is always kept of proper size to maintain the balance, but there is no doubt that the better commercial form is the four-wire secondary, or in fact, the two phases taken directly from the machine to the customer's service. With the same number of conductors, a further saving of copper is secured by the use of the four-wire, three-phase. With either of these systems, where transformers are a part of the individual feeder, a complete interconnection of mains can be secured. When the supply from these secondary mains is introduced into the premises of the customer, necessity for installation of additional transforming apparatus arises. If the secondary be of a pressure of 110 volts between phases, either large motors must be installed at this pressure or step-up transformers used. In either case the mains must be very large to take care of this low pressure motor current, and especially when such multiphase motors are frequently stopped and started. If the secondary be of a pressure of 220 volts, the size of conductors can of course be reduced; but it is still necessary to install a transformer or balancing device if 110-volt arc or incandescent lamps are used.

With the object of simplifying the system, in many cases the multiple network of secondary mains has been omitted, and in their place a multiple network of primary mains substituted, the transformers being located on the premises of the customers. This reduces the system to a house-to house supply and makes necessary the building of vaults or in other ways satisfying the insurance companies, as the full pressure is introduced into the premises of the customer. Such an arrangement necessitates an increase in the transformer capacity of the system, since the capacity of the transformers must be nearer the capacity of the connected load; whereas if grouped and the supply furnished through secondary mains, the transformer capacity can approach nearer the actual maximum load of the system.

In order to reduce the fluctuations of pressure in the lighting circuit, caused by large direct-connected alternating current mo-

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tors stopping and starting, there have been devised several systems which provide separate means of supply for motors and for lights, by providing additional "power" conductors, but in nearly all cases such systems necessitate the installation of primary transformers on the premises of the customer. With a view of furnishing a single service to the customer without installing apparatus on the premises, there are one or two systems employing four or five low-tension conductors in the secondary, from which different combinations of pressure are secured for the separate operation of motors and lights, but such systems have not been put to extended central station use.

But if the alternating system has not yet attained the standard of a large distributing system for compact territory, it is nevertheless alone in its field of transmission and house-to-house supply in scattered territory, and yet even in these fields too much attention cannot be paid to the consideration of future permanent supply, there being many cases of its having been used as a very temporary means of "getting there." A generator is bought, a few miles of small-sized conductors erected, enough transformer capacity installed to supply the present wants, and the installation is complete and trouble begins. When extra transformers are required, they are purchased one by one in small sizes and connected to feeders already too small to carry the load. The idea of a change in the size of conductors never occurs, and soon the station manager does not think much of the alternating system, and by that time the public generally agrees with him. This state of conditions is due to the fact that the system has not been designed with an idea of permanency, and the future and uncalculated demand upon it completely destroys its usefulness. Such a state of affairs existed in the pioneer days of direct current engineering, the future demands seldom receiving the consideration which they warranted. Inspectors "determined" the system and visited every corner of the city, every private house, hotel, etc., and finally "determined" that the heaviest direct current mains in the business section should be 27,000 c. m. and the feeder 41,000 c. m. Three years later, in the same city, these mains were replaced by others of eight times the capacity, and were even then too small. Such was true of the simple direct current system, and it was even more true of the alternating system. The idea that the alternating high-pressure system saves copper, and that therefore it may be possible to save it all, has often brought about a final failure of a promising success.

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What is required to-day, however, if the alternating current, besides retaining its field of transmission and scattered distribution where it is supreme, would enter the compact direct-current field of distribution, is:

First.—A standard type of motor, which can be used for all classes of business demand, and will meet the same commercial requirements as the present direct-current motor.

Second.—A universal system of supply which does not require transformers, etc., or anything outside of the meter itself, to be located on the premises of the customers.

Third.—Some apparatus which, in connection with alternating current, will take the place of the storage battery supply on the direct current.

With these requirements complied with, the alternating current distributing systems can expect to take the place of many of the large direct-current systems, not only for the supplying of light, heat and power but also for transportation.

November 12, 1901.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

DISTRIBUTION OF ELECTRICITY IN CITIES OF MODERATE SIZE.

BY WILLIAM LISPENARD ROBB.

In dealing with the question of the distribution of electricity it is impossible to lay down any but very general principles that will apply to many actual cases. Each individual case will be governed largely by existing local conditions. Much that would be desirable if a plant were being laid out new is found impracticable when the conditions of an existing plant are taken into account.

Cities naturally divide themselves into groups according to population, and for the purposes of this paper I have considered "cities of moderate size" as including those having a population of two hundred thousand or less. A satisfactory solution of the problem of electrical distribution is manifestly different in cities of this class from that in the large metropolitan cities.

Indeed, in dealing with the problem in cities of moderate size, a system of distribution that would be satisfactory for the smaller cities of the class would not meet all the requirements of the larger cities. No exact limitation can be placed as to the point at which the requirements materially change, as they are largely governed by local conditions other than population. It seems to me, however, that cities having less than about 50,000 inhabitants make a class by themselves.

In cities of less than 50,000 inhabitants a very considerable area has to be lighted, in general extending out from two to three miles in all directions from the central station. In a con-

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siderable portion of the city electricity will be required only for street lighting. Then fifty to one hundred miles of street will have to be lighted, and arc lighting will generally be required for this service. It will be necessary to supply electricity for incandescent and arc lighting and power whenever desired. In general in the cities of this class there will be practically no tendency to put in isolated plants. There will be found little, if any, objection to overhead wires. If any wires should be required to be placed under ground it will be only in a very limited section of the city, and the total amount of electrical energy supply from the underground wires would be small. The commercial lighting and power in a city of this class would not be concentrated but scattered over several square miles. The demand for variable speed motors would be too small to be taken into account. The total amount of electrical energy would be too small to warrant the maintenance of more than a single station.

Under all these conditions it seems to me that only three-phase alternating current, having a frequency of 60-cycles and under a pressure of about 2,300 volts should be generated.

The street arc lighting should be by constant current series enclosed arc lamps. The distribution for lighting would in general be single phase, and if only motors of three h. p. or under were used, it would be best to operate the motors from the single-phase lighting system. My own experience has been that single-phase motors above this size are not satisfactory as compared with polyphase motors, and will not meet all the requirements. Any city central station should be capable of supplying power for any purpose, and should be able to supply current for electrolytic and storage battery work. When the motors required are large, three phase motors should be used, and three phase rotary converters installed on the customer's premises should be used for electrolytic purposes. The city should be divided into sections, and the different sections supplied from the different phases. If at any one point in any section large motors or rotary converters are required the additional primary wire would be brought from the nearest point in the adjoining section. Satisfactory service will be given with light and motors supplied from the same circuits.

In sections where there is any concentration of lighting and power, a 220-volt three-wire system of secondary wiring should

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be used, and be supplied if the system is small from a single transformer, or, if the system is large, from transformers suitably located at several points. I do not think it would be found desirable in practice to cut out any of these transformers during the hours of light load.

In the larger of the cities of moderate size a different set of conditions exist, and the problem of electric distribution is very materially modified. The area lighted is very large, and while commercial lighting and power is concentrated in sections, lighting and power service has to be supplied in practically all parts of the city. There is a tendency for the department stores, office buildings and large manufacturing industries to put in their own electric plants, and there is a growing demand for the wires in the business section to be put underground.

In cities of this class there are generally two sections where the demand for electricity is concentrated—the business section —where are located the large stores and office buildings and the manufactories district. Each of these sections has its own characteristics. In the business district the use of the large motor is largely confined to elevator and other service where the load is exceedingly variable and intermittent, and at the same time the very best lighting service is insisted upon, both as regards the constancy of the lights and the absolute certainty of the service. As a rule, in the manufacturing district, the percentage variation in load on the motor service is very much less than in the business section, the only variation that seriously affects the lights occurring when the machinery is started in the morning and after the noon hour. At these times there is practically no lighting. While the demand that the wires in the business section should be placed underground must be heeded, there is practically no demand for it in manufacturing districts.

The central station should be located at a point where coal can be delivered directly from the boat or railroad, and where water for condensing can be readily obtained. In nearly all places this means that the generating station will be situated a considerable distance from the business section of the city. The conditions existing in the business section of a city of this class, as against the concentration of load, the intermittent character of the motor load, the necessity and desirability of underground wires, the existing investment of central station and customers in direct current apparatus, isolated plants and the relatively

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high price charged at present for alternating currents and arc lamps, motors, etc., make it desirable to supply the business section at the present time with direct current.

Considering that it is desirable to supply both commercial incandescent and arc lighting and also motors from the same system of wiring, it seems best that the current should be distributed on the three-wire 220-volt system. This voltage is preferable to a 440-volt system, as in my opinion the saving in copper required for the distribution, if the higher voltage is used, is much more than counterbalanced by the inferiority of the 220-volt arc and incandescent lamps as compared with the corresponding 110-volt lamps.

In general, the situation of the power-house most suitable for the cheap production of electricity will not be in the business district. The needs of a city of moderate size would also not justify the operation of two power-houses. The electricity for the business district should therefore in general be supplied from a rotary converter sub-station, situated as near as possible to the center of distribution of the business district.

The main power-house should generate only alternating current. This should have a frequency of 60-cycles, be a three-phase four-wire system, and have a pressure of approximately 2,300 volts between each phase wire and the common wire. The four-wire three-phase system is preferred, owing to the saving of copper, over other systems that would prevent the using of standard 2,300-volt transformers and other standard line materials. Sixty cycles should be used, as arc lamp motors, incandescent lamps and rotary converters for supplying the 220-volt direct current, can all be operated satisfactorily at this frequency, and at no other frequency at which generators are now made commercially.

The electricity from the power-house to the rotary sub-station should be transmitted on the three-phase wire, the common fourth wire being omitted. Boosters would not be required, and the pressure in the d. c. side of the rotaries would be varied by means of the static transformers used in connection with the rotaries.

The direct current distribution from the sub-station should be underground. Not only is this demanded by the public, but in the business section of the large cities, I believe that, interest or investment cost of maintenance taken into account, it is decidedly cheaper as well as much more satisfactory to maintain an underground than an overhead system of distribution.

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The feeders should be lead-covered cables drawn into conduits, as feeders are liable to have for short periods considerable overloads, and there are no branches to be tapped off. I believe paper insulation is more satisfactory as well as cheaper for feeders than rubber.

The distribution boxes should be of the manhole type, or better still, of the lamp-post type. The old style of Edison box blocks traffic too much to be installed at the present time.

When frequent services have to be made there is nothing so satisfactory as the old Edison tubes. When the services are infrequent the most satisfactory system is to use lead-covered rubber insulated cable drawn in ducts as distributing mains, carrying a single service into each building from a small distributing box placed at every other property line. Arc lighting, incandescent lighting and power should all be supplied from the same system of distribution.

Outside of the business section the electricity should be supplied for all purposes on the alternating current system. The current should be taken to the power-house from various distributing centers on the four-wire three-phase system. From these centers of distribution single-phase circuits should be run for the operation of commercial arc and incandescent lighting and small motors. Additional phase-wires would have to be taken from the centers of distribution to manufacturing plants where large motors were used.

When the lighting is at all concentrated, the lighting and motors should be supplied from three-wire 220-volt secondary mains, fed by large transformers, and it will be found desirable to thoroughly ground the neutral wire.

The street lighting should be by series constant current arc lamps. In some cases it would be desirable to supply the current for these from transforming devices located at the central power-house. In other cases the transforming devices could be most advantageously located at the centers of alternating current distribution, as thereby the number of wires could be materially reduced, a few large wires taking the place of a very much larger number of small wires.

In order that a system of alternating current distribution of any size should be satisfactory, it is necessary that the arrangement of the power-house be such that current be supplied to the different feeders at different pressures. This can be done by

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boosting transformers in each feeder circuit, and by a system of pressure wires brought back to the power-house from the various centers of distribution, or by the automatic device of Mr. W. L. R. Emmet.

The succes-ful introduction of the Nernst lamp into the fields of incandescent and arc lighting, and the development of the steam turbine, should have a marked effect in favor of the generating and distribution of alternating current. On the other hand, the air is full of rumors of marked improvements in storage batteries.

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A paper read at the 158th Meeting of the American Institute of Electrical Engineers, New York and Chicago, November 22, 1901.

250-VOLT THREE-WIRE DISTRIBUTION FOR LIGHTING AND POWER.

BY PHILIPPO TORCHIO.

In the last few years great improvements have been made in the manufacture and selection of incandescent lamps. The arc lamp practice has undergone a radical change. The wiring and appliances connected with electric installations of buildings and other places have been brought up to a high standard of good workmanship and insulation. These, and other not less important improvements, have made possible the use of commercial voltages considerably higher than were permitted in the early stages of the industry of electric lighting and power distribution.

In existing well developed systems of low-tension current distribution it would be out of the question to consider at this date the proposition of changing the voltage of established systems, but on new installations and in places where changes of systems of distribution are contemplated it is sometimes convenient to adopt the three-wire 500-volt system which has met with great favor abroad, and especially in England, and which is gradually being introduced in this country. In its favor are the following points:

The system has all the advantages of the original low-tension Edison three-wire system, and it has greater capabilities of expansion in lightly loaded or scattered territories, as is often the case in small cities or in large factories and other places. The system is economical to operate, it is economical as to distribution within a wide radius, it is flexible and easy of control and

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simple of operation, and free from such troubles as capacity and inductive effects which appear on A. C. transmission lines and translating devices; it can be applied directly to a greater variety of services than any other system, and finally it derives from the use of the storage battery economical advantages in station investment and the invaluable commercial superiority of ensuring continuity of service.

The generating equipment and the station apparatus for 500-volt systems is just as well developed as any other apparatus on the market, and the cost is well in line with other standard apparatus.

The main unfavorable points of the 500-volt three-wire system are (*a*) the increased tendency to arc, necessitating the use of wiring and appliances of high insulation and carefully separated terminals at the customers' installation, (*b*) the lower efficiency of the 250-volt incandescent lamps as compared with lamps of half that voltage, (*c*) the difficulty of operating 250-volt arc lamps.

These limitations are gradually becoming less and less restrictive, as a review of the present conditions will demonstrate.

As to the insulation requirements for wiring and appliances, the new rules of the National Board of Underwriters prescribe the same insulation and breakdown test for all wires used with voltages between 0 and 600; all lamp sockets and receptacles must be suitable for use on any voltage up to 250 volts, only rosettes, cleats, knife and snap switches, etc., are required to be special for voltages between 250 and 600. In general, it may be said that any modern installation will safely withstand a 500-volt service, and that the conservative requirements of the Board of Fire Underwriters are not uncommercially stringent. It may, however, be said that not all the local Boards of Fire Underwriters have as yet adopted the rules of the National Board.

In regard to efficiency of high voltage incandescent lamps, the difference for the standard 16 C. P. lamp of same candle hour area as the low voltage lamp is about 10 per cent. The best 200–250-volt 16 C. P. lamps made at present have an initial efficiency of 3.4 watts per candle, and have the same life as the 3.1 watt per candle 110–125-volt lamp.

In large cities supplied by Edison system, the common practice is to use lamps of 3.1 watts per candle; in all other places, lower efficiency lamps are ordinarily used, and the 3.6 watts per candle lamp is quite common. In the latter case the adoption of

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a 3.4–3.5 w. p. c. 250 volt lamp would not materially overtax the user nor the illuminating company, and therefore, for such places the 500-volt three wire system would not be at a disadvantage on that account.

The difficulty of adapting arc lamps to the 500 volt three-wire system has been overcome by connecting two ordinary enclosed arc lamps in series in the same manner that the old open arcs were, and are still, in many places, connected on the 110-volt circuits. Lately, however, several types of double arc lamps have been used with entire success. The single arc has also been tried to some extent, but it has proved a failure for general use on account of the objectionable blue light it gives. Such lamps are, however, used for street lighting in a few places.

The review of the difficulties to be overcome shows that they are not very serious, especially for new installations and where changes of distribution are contemplated.

In some calculations recently made to show the economic relations between this system and the ordinary 250-v. three-wire system it was shown that the savings are very large for lightly loaded districts. In the following table (I) are given the different assumptions made and steps followed in the calculation, which were as follows:

First column gives density of distribution per foot of street—*i. e.*, watts maximum load per foot of street.

Column (I) gives total length of streets covered by mains per square mile, to which unit are referred all following calculations. The assumption was made that in American cities there are on the average 25 miles of streets built per square mile of territory, exclusive of parks and open places. In the business and crowded sections it was assumed that practically all the streets are covered by mains. In less dense districts only a portion of streets are so covered by mains.

Column (II) gives the maximum load per square mile as obtained from the previous assumptions.

Column (III) shows one layout of feeders which might be representative of common practice for an ordinary 250-v. three-wire system. This is done to arrive at the length of mains to be supplied from each feeding point, as shown in column (VI), assuming conditions given in columns (IV) and (V).

Column (VII A) gives maximum amperes per outlet of mains.

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TABLE I.

Watts max. load per foot of street covered by mains.	I. Length of streets covered by mains per square mile.		II. Maximum load per square mile.		III. Feeders required for 250 V. 3. W. distrib. with 660 A. density per 1,000,000 C. M.		IV. Average Feeding Points.		V. No. of Outlets.		VI. Average feet of mains per outlet.	VII. A. Amperes max. per outlet of mains 250 V. 3. W. distrib.	VIII. A. Average cross section of mains used if no large motors were conn. 250 V. 3 W. 1.6% Regulation = 4 V. over 250 V. c. m.
	Miles	Feet.	K. W.	Amp. at 250 V.	No.	Average Size C. M.	Per Feeder.	Total.	Per Feeding Point.	Total.			
2.5	12.5	66,000	165	660	4	250,000	3	12	3	36	1,835	18.4	92,500
5	12.5	66,000	330	1,320	4	500,000	3	12	3	36	1,835	36.7	185,000
10	18¾	99,000	990	3,960	12	500,000	2	24	3	72	1,375	55.0	208,000
20	25	132,000	2,640	10,560	24	666,000	1	24	4	96	1,375	110.0	416,000
40	25	132,000	5,280	21,120	32	1,000,000	1	32	4	128	1,030	165.0	468,000
80	25	132,000	10,560	42,240	64	1,000,000	1	64	4	256	515	165.0	234,000

CONTINUED. Watts max. load per foot of street covered by mains.	IX. A. Lbs. of copper for 3-cable mains 250 V. 3 W. dist.	X. A. Lbs. of copper saved if 500 V. 3 W. dist. were used (75% of IX. A.)	XI. A. Annual saving at 25c. per lb. of copper in Cable and 7% Int. and Dep.	VII. B. Max. current allowance for large motors connected above normal current of column VII. A.		VIII. B. Average cross section of mains used if large motors were conn. 250 V. 3 W. 1.6% Regulation = 4 V. over 250 V. c. m.	IX. B. Lbs. of copper for 3-cable mains 250 V. 3 W. distrib.	X. B. Lbs. of copper saved if 500 V. 3 W. dist. were used (75% of IX. B.)	XI. B. Annual saving at 25c. per lb. of copper in Cable and 7% Int. and Dep.
				Amps. at 250 V.	K. W.				
2.5	54,945	41,208	$721	18.4	4.6	185,000	103,890	82,416	$1,442
5	109,890	82,416	1,442	18.4	4.6	277,500	164,835	123,624	2,162
10	185,328	138,996	2,432	27.5	6.9	312,000	277,992	208,494	3,648
20	494,208	370,656	6,486	55.0	13.8	624,000	741,312	555,984	9,729
40	555,984	416,988	7,297	82.5	20 6	702,000	833,976	625,482	10,945
80	277,992	208,494	3,648	165.0	41.2	468,000	555,984	416,988	7,297

CONTINUED. Watts max. load per foot of street covered by mains.	XII. Square miles of Territory covered by one distrib. station.		XIII. Estimated saving of substation per square mile of 500 V. 3 W.	XIV. Annual saving Int. and Dep. at 6% and taxes at 2%	XV. Annual saving of operation per sq. mile of 500 V. 3 W.	XVI. A. Total annual saving per square mile XI. A. + XIV. + XV. without large motors.	XVI. B. Total annual saving per square mile XI. B. + XIV. + XV. with large motors.	XVII. Total K. W. Hours delivered per square mile at the load factor marked.		XVIII. Total saving per K. W. Hr. delivered.	
	250 V. 3 W.	500V. 3 W.						L. F.	K. W. Hrs.	Without large motors.	With large motors.
2.5	4	16	$6 250	$500	$750	$1,996	$2,717	20%	289,080	.692c	.940c
5	4	16	7,812	624	750	2,816	3,537	20%	578,160	.488	.612
10	2	8	15,625	1,248	1,500	5,180	6,396	25%	2,168,100	.239	.295
20	1	4	31,250	2,496	3,000	11,982	15,225	25%	5,781,600	.207	.263
40	.75	3	50,000	4,000	4,000	15,297	18,945	25%	11,563,200	.132	.164
80	.5	2	100,000	8,000	6,000	17,648	21,297	25%	23,126,460	.076	.092

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Column (VIII A) gives cross-section of each outlet for 1.6 per cent. regulation, assuming its load evenly distributed.

Column (IX A) gives the weight of copper required for mains as determined for the above cross-section.

In column (X A) is given the saving of copper which would be realized if a 500-v. three-wire system had been used instead of the 250-v. three-wire, for same conditions in both instances.

Column (XI A) reduces the copper saving to saving per annum on an assumed basis of cost of copper in case of underground cables, which cost includes a rough estimate of the cost of insulation and lead sheet. In case of overhead lines this saving should have been about one-third less.

In columns (VII B), (VIII B), (IX B), (X B), (XI B) are given on similar lines the calculations of savings for systems operating motors from the lighting mains, assuming to maintain the same regulation of 1.6 per cent. for the specified momentary inrush of current due to motors for each main. This calculation is not accurate, but will not materially offset the relative results under discussion.

Column (XII) gives an estimate of the territory which can be economically covered by a low-tension station, so as to arrive at the savings of station investment. Only a few years ago, before the introduction of the rotary and inverted rotary converters and composite D.C. and A.C. generators, it would have been impossible to concentrate in one station the production of current for the whole system, and therefore, to study the general problem which we have now under discussion, it would have been necessary to introduce the consideration of building and operating separate L. T. generating stations to cover a certain limited territory. This is no longer the case, as only in comparatively few cases in the lighting situation will it pay to operate more than one generating station, except in the case of very large cities covering hundreds of square miles of territory. Under the present conditions the determination of the number of distributing sub-stations is onlya matter of balancing the cost of L. T. feeders and other factors entering the cost of distribution against the extra cost at a new substation and its operation. Under column (XII) is given a rough approximation of the square miles of territory that could be economically supplied by L. T. sub-stations under given conditions It will be noticed that with a 500-v. three-wire system a substation can in each case supply for same current density in feeders

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and same regulation a territory four times as large as with a 250-v. three-wire system. Under these conditions, which are approximately the most economical, the amount of copper for feeders will *be the same for both systems.* There will, therefore, be no saving of copper for feeders in favor of the 500-v. system. While no feeder saving is effected by the 500-v. system, a large saving will be made by the reduction of the number of substations and their operating expenses, which savings per annum are estimated as given in columns (XIV) and (XV).

The following columns (XVI A) and (XVI B) give the sum of all savings, and the last two columns the same, prorated to each K. W. hour delivered for specified commercial load factors :

TABLE II.

Watts Max. Load per foot of Street covered by Mains.	Copper Investment Saving. X. A. No Large Motors.	Copper Investment Saving. X. B. With Large Motors.	Est. Saving of Substation. XIII.	Total Investment Saving. A. No Large Motors.	Total Investment Saving. B. With Large Motors.	Total Investment Saving per K. W. Max.	
						A. No Large Motors.	B. With Large Motors.
2.5	$10,302	$20,604	$6,250	$16,552	$26,854	$100 00	$162 50
5	20,604	30,906	7,812	28,416	38,718	86 00	117 00
10	34,749	52,123	15,625	50,374	67,748	51 00	68 50
20	97,604	138,996	31,250	123,914	170,246	47 00	64 50
40	104,247	156,370	50,000	154,247	206,378	29 20	39 20
80	52,123	104,247	100,000	152,123	204,247	14 40	19 40

In these calculations we have assumed that the station machinery would have the same unit cost per K. W. capacity in both systems. The total capacity will be the same in both cases.

We have not taken into account the question of subway ducts, as we have assumed the cost of distributing ducts to be independent of the size of mains. In the case of trunk ducts for feeders we have assumed to require the same number of duct feet in both cases. This will not be the case in actual practice, as while with the two systems we have the same amount of copper to lay in ducts, still in the case of 250-v. system this copper can be better distributed in large cables to fill up the whole duct capacity, while in the case of 500-v. system the copper must be distributed in smaller cables, which cannot be made to utilize as fully the capacity of the ducts. This fact would offset some of the savings for the 500-v. system given in the table.

In case of overhead lines it has already been noted that the savings for copper would be about one-third less than given in

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the table. Furthermore, in actual practice the size of 500-v. mains would usually be selected with a more liberal margin than for the 250-v. mains. Therefore, the savings given in table represent *the maximum theoretical savings in favor of the* 500-v. *three-wire system* under the specific conditions therein assumed.

These savings are greater in lightly-loaded districts, where we have already stated that, in general, low-efficiency lamps are more suitable. Therefore, if the efficiency and life of 200–250-v. lamps are practically the same as for the low-voltage lamps, the company can supply the same number of lamps of the two types per K. W. capacity of station machinery and distributing feeders and mains; the customer will consume the same amount of current for the same amount of light, and therefore the savings in favor of the 500-v. three-wire system given in the previous table represent actual net savings to the company. If the system has arc lamps and motors connected, the saving per K. W. hour delivered for those classes of services will also be net savings to the company.

It will be found that in general these conditions are mostly common in the out-lying districts of large cities and in the majority of small towns. In many of these cases I think that a 500-v. three-wire system would be entirely successful and present economical advantages. A further advantage in these cases is the relative large saving in investment per K. W. added in favor of the 500-v. system over a 250-v. system. This is shown in table (II), obtained from the data of the previous table.

The savings in investment in lightly-loaded districts go up in the hundreds of dollars per K. W. load added, and if the district is not expected to reach higher densities it is clear that the advantages of a 500-v. three-wire system are very great, especially if, as is often the case, there is a considerable number of small motors for residence elevators and small factories and shops, but not sufficient to warrant the installation of a separate power circuit to cover such a scattered territory.

In heavier load districts the savings are considerably smaller, and represent an insignificant proportion of the total business, as shown in table (I), comparing the total savings of columns (XVI A) and (XVI B) with the total K. W. hours sold, as per column (XVII). Besides, in larger systems, it is important to use the most efficient lamp which can be commercially operated, and

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this further consideration excludes the use of high-voltage lamps, independently of any consideration of the difficulties and expenses involved in the proposition of readjusting to the higher voltage the existing station machinery, storage batteries and switchboard equipments, and also the customers' installations of arc lamps, motors, and a large proportion of wiring and appliances.

The 500-v. three-wire system has found a special favor in England, principally on account of the local practice of not supplying customers with free renewal of lamps, which has created a condition where only low-efficiency lamps could be operated satisfactorily. Few lamps in England, only three or four years ago, had a higher efficiency than 4 w. p. c. Most lamps in use were old lamps of an efficiency of 5, 6 or 7 w. p. c., and in many cases companies started off with free new 250-v. lamps at 4 w. p. c., giving a positive saving. The 500-v. system has been adopted in several places in this country, among which the most prominent instance is the system of the Narragansett Electric Light Company, of Providence, R. I., operating a 470-v. three-wire system. The experience of this company has unquestionably proved the practicability of the 500-v. three-wire system in small cities and towns under conditions existing in America.

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Discussion.

THE PRESIDENT:—I may state that the paper of Mr. Emmet, who is not present to read it, deals with the methods devised to combine the extreme simplicity of the single-phase alternating current system with the efficiency of generation and distribution of the polyphase system, by the use of three-phase generators operating single-phase lighting combined with three-phase power, either by having a four-wire primary distribution with single-phase secondary circuits as outlined by Mr. Ferguson, or by operating a three-wire single-phase secondary, utilizing a fourth wire for motor supply. Mr. Emmet's paper also discusses the four-wire balanced three-phase secondary system of distribution.

The paper of Mr. Robb, who is also absent, describes the means for distribution of electricity in cities of moderate size, and comes to the conclusion that for smaller cities the most desirable system is the three-phase, sixty-cycle alternating current system with overhead distribution, using single-phase secondary and four-wire primaries, and operating single-phase lighting and power in small motors, while larger motors are operated on the three-phase system.

In somewhat larger cities, but still of moderate size, Mr. Robb recommends the introduction of a central continuous current distribution by underground three-wire mains, fed from the alternating system by rotary converters or other suitable means.

It is very interesting to note, in comparing this paper of Mr. Robb's with Mr. Ferguson's paper, that while starting from two opposite directions—on the one side, from the supply of a very large city by continuous currents, three-wire underground mains, gradually reaching out to the supplemental alternating current, sixty-cycle system, and on the other side by supplying a small city with alternating current, and gradually adding for the concentrated central district a continuous current distribution—the ways and means and the systems recommended by both authors are identically the same; the same four-wire, sixty-cycle, three-phase primary distribution, with single phase secondaries for the alternating part and the three-wire underground continuous current system for the continuous current part. The only difference is that due to the difference in the relative proportions of the two parts, the continuous current preponderating by far in the large cities, while the alternating current is the only system used in the very small cities, or the preponderating system in a moderate sized city. In moderate sized cities the continuous current system is operated from the sixty-cycle alternating system by converters or other appliances, while in the very large cities the alternating current system is operated from the continuous current system by converters; or both systems operated together from the same primary generating system of low frequency—twenty-five cycles. As I said

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before, this is the more encouraging, as it shows that electrical distribution has reached a definite standard, since prominent electrical engineers, starting from oppositely different points, arrive at the same result.

MR. GANO S. DUNN:—Mr. Chairman and gentlemen, I have listened with intersest to the papers which have been read, and while I do not wish to be controversial, I cannot agree with some of the views expressed by Mr. Scott, and I have therefore selected two points in his paper upon which I wish to speak. I have also a lantern slide, which I wish to show if time permits:

On page 845 of Mr. Scott's paper he says:—

"For variable speed work the conditions are different, the fundamental difference is due to the fact that although there is a close correspondence between the performance of the induction motor and the direct current shunt motor with constant field excitation, the alternating current motor does not have an exact analogue to the direct current series motor."

This implies that the induction motor is to a large degree an analogue to the shunt motor. The analogy is much more limited than is usually supposed, and I wish to point out its imperfection.

In the first place, as Mr. Scott has stated, the analogy is limited to a machine, with constant field excitation. By that limitation he rules out one of the principal advantages of the shunt machine which is that you can control its speed by controlling its field. To this there is no analogue in the induction motor.

The second point by which the induction motor is not analogous to the shunt motor is that you can control the speed of a shunt motor by controlling the voltage on its armature. But you cannot in anywise do this with the induction motor.

The matter of speed control, far from being insignificant, is a very important element in the constitution of power plants to-day, and because in the past we have been accustomed to fixed speed, we must not think that in the future we shall be contented with it where we can have motors that will give us throughout wide ranges, speeds controlled with perfect efficiency and stability. Multiple voltage systems are rapidly coming into use and only direct current motors can be operated with success on them.

A system that has four wires, by different combinations of them can give about six speeds, and by variations of field strength or a small amount of armature resistance can be made to give easily twelve or more speeds, all with practical efficiency and stability.

Further up on the same page Mr. Scott says:

"For constant speed work probably no one will question the superiority of the alternating current motor from the standpoint of the man who uses the motor and pays for repairs. Any objections which may be brought forward will probably be urged on account of reasons applying to the supply system such as

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power factor, starting current and voltage regulation. These items may be provided for by properly designing the system, and they cannot be regarded as legitimate objections to the use of the alternating current motor."

With the last statement I differ, because if you properly design the system as he suggests, the cost of it runs away up out of proportion to what you are going to use it for, and no matter what has caused it, the high cost, if it is accompanying the use of the motor, might as well be charged to the motor.

I have a lantern slide here which was not prepared for this discussion but which shows the relative performance of constant speed motors, induction and direct current, and if I have time I should like to show it.

(Slide showing curves exhibited. See page 872.)

The three sets of curves show the performance of the motors with respect to running current, efficiency and speed. The abscissae are torques expressed in percentage of full load running torques, and the heavy line at 100 per cent. represents normal full load for all the motors. The ordinates are current, efficiency and speed, also expressed in percentages, for comparison.

The speed and current tests of the direct current motors were made by applying a Prony brake to the motor running free and gradually tightening it until the motor stalled.

You will note that at full load the running current of the induction motor is about 10 per cent. greater than that of the direct current motors. The starting current for the induction motor is at the mark "x," and is nearly twice as much as required to give the same torque in the direct current motors. The efficiencies of all the motors are about the same up to two-thirds load, after which the induction motor efficiency falls off very rapidly while the direct current motor efficiencies are tolerably well maintained. The speed curves, which originate in the upper left hand corner, show that at full load the shunt motor falls off about 4½ per cent., the induction motor about 6 per cent. and the compound motor about 7½ per cent. At 2.6 times normal torque, the induction motor, however, stalls, while both of the direct current machines continue to run, the shunt motor until its torque reaches 6.4 times normal torque and the compound motor 10.8 times normal torque. In the middle ranges of these speed curves of the direct current motors there was sparking, but beyond the middle, at the points of severest overloads, the sparking almost disappeared, because the speeds were so low that the commutation reactance was greatly reduced. The sparking that was present in the middle ranges was not such as would injure the commutator unless the severe overloads were maintained.

It might be argued that the compound motor does not belong in this comparison because it is not a constant speed motor. I submit, however, that a motor whose regulation is 7½ per cent.

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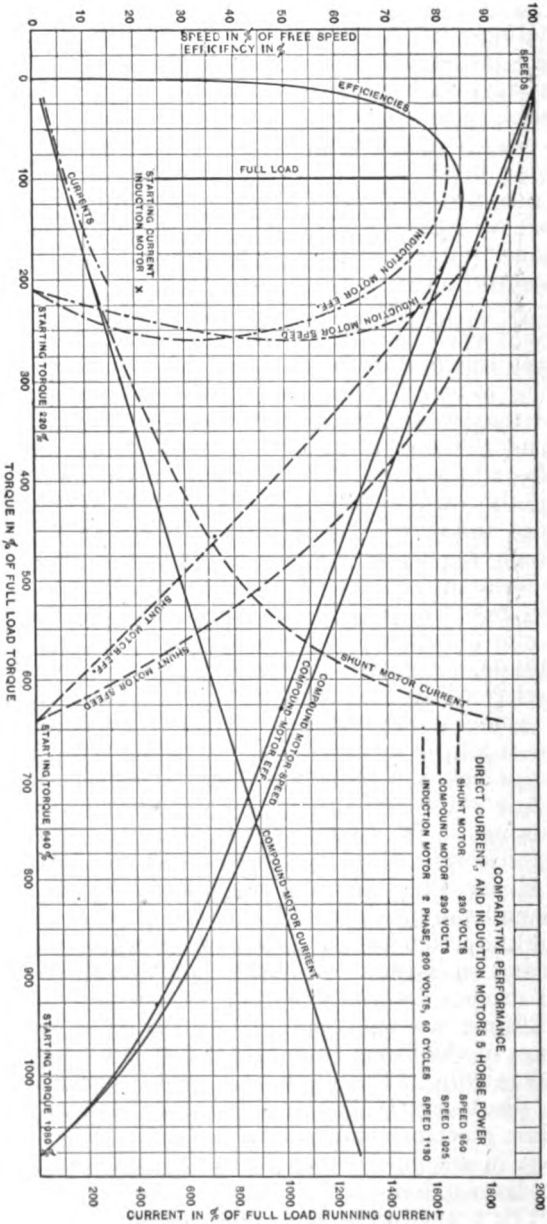
SPEED IN % OF FREE SPEED
EFFICIENCY IN %
SPEEDS
EFFICIENCIES
FULL LOAD
CURRENTS
STARTING CURRENT INDUCTION MOTOR
INDUCTION MOTOR EFF.
INDUCTION MOTOR SPEED
STARTING TORQUE 220 %
SHUNT MOTOR EFF.
SHUNT MOTOR SPEED
SHUNT MOTOR CURRENT
COMPOUND MOTOR SPEED
COMPOUND MOTOR EFF.
COMPOUND MOTOR CURRENT
STARTING TORQUE 440 %
STARTING TORQUE 1200 %
TORQUE IN % OF FULL LOAD TORQUE
CURRENT IN % OF FULL LOAD RUNNING CURRENT
COMPARATIVE PERFORMANCE
DIRECT CURRENT, AND INDUCTION MOTORS 5 HORSE POWER
SHUNT MOTOR 230 VOLTS SPEED 1650
COMPOUND MOTOR 230 VOLTS SPEED 1625
INDUCTION MOTOR 2 PHASE, 200 VOLTS, 60 CYCLES SPEED 1190

Curves showing relative performance of motors.

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ought to come under this category, especially as its use for constant speed work is rapidly increasing.

It may also be argued that the region of these curves beyond 2.6 times normal torque, does not indicate useful properties in the motors. This position cannot be maintained. In steel mills and similar factories, the overloads are frequent and very severe, and it is just the region of the curves in question that causes direct current motors to be appreciated for this service. For induction motors to give equivalent service, much larger sizes would have to be installed, which together with the fact that the cost per horse power is greater, would make the cost of installation very much greater.

It has been shown by other speakers that this extended region of the curves is what has thrown the elevator business into direct current, and in my opinion it is this region which has exerted a controlling effect in other ways upon the development of the two systems of distribution.

When you sum up, it seems to me you reach this point; the direct current motor may require a little closer attention, but it is a great deal cheaper and can do a great deal more.

MR. LOUIS A. FERGUSON:—In listening, Mr. President and gentlemen, to Mr. Scott's paper, there were a few things that rather surprised me and I feel as if I might take exception to some of his statements.

On page 843 under the heading (1) he says that—

"Converting apparatus requires rotating machinery and the presence of attendants, and these involve first cost, operating expense, complication, and liability to interruption of service."

I would like to say in regard to that, that from our experience the operating expense of sub-stations is a mere bagatelle, and while I have not the figures at hand with me, I might say that the operation is usually accomplished by one man and runs only into the hundredths of a cent per kilowatt hour, so it cannot be a very serious objection.

On page 844 the question of arc lighting is mentioned, and he says there that—

"Arc lighting is most extensively carried on by the enclosed arc lamp, which is satisfactorily operated from direct current circuits and also from sixty-cycle alternating circuits, so that there is no compelling reason for choosing either one current or the other as far as arc lamps are concerned."

My objection to that is only slight. Of course, the power factor of alternating arc lamps is about seventy or seventy-five per cent., and the inside wiring required for alternating current lamps is greater than that required for direct current. Where alternating current lamps are put in substitution for the direct current lamps, it is found necessary to increase the size of the wiring.

He says: "The Nernst lamp, which is quite satisfactory in its

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operation on alternating current, but not on direct current, gives a positive reason for choosing the former."

It seems to me that if the same amount of brains and energy were expended in developing the Nernst lamp for direct current work as have been expended for the alternating current, we might have a better Nernst lamp for direct current work, and I think that is something we may look for in the future.

Those two items that Mr. Dunn spoke of were things that I intended to speak about, so that I will only mention them. That is, on page 845 he says:

"These items may be provided for by properly designing the system, and they cannot be regarded as legitimate objections to the use of the alternating current motor."

In order to accomplish the same results with alternating current motors that we do with direct current, it is necessary to spend a great deal of money on the distribution system, and if I am correctly informed, most of the companies that do any considerable business in alternating current motor work use separate systems of distribution circuits for lighting and for power, and I think that is done in New York.

In regard to the matter of variable speed work, which was very well brought out by Mr. Dunn, I had in mind speaking of the multiple voltage system, which he mentioned.

Regarding the question of elevators, I would like to emphasize the fact that we have not at the present time, and there does not seem to be much hope of having in the future, alternating current elevators that are at all comparable with the direct-current elevator. I personally would be very glad to see them, because we need a first-class alternating current elevator, but it simply is not to be had. The primary reason for it is that you cannot get a variable speed alternating-current motor. The stopping of alternating-current elevators is exceedingly poor, and is due to the fact that it must be accomplished by means of the mechanical brake after the current is cut off, and of course therefore it is very rough, indeed. It is very difficult sometimes to convince customers that they should put in alternating current elevators, and, instead of doing so, they install hydraulic elevators. The rotating parts of the alternating current motor are also heavier than the direct-current rotating parts, and this of course adds to the difficulty in making good stops. The starting of the elevators is also poor. The very fact that you have to stop the alternating current elevator by means of the brake limits its speed, so that at the present time we are only able to have elevators run at about 150 or 160 feet a minute, although some people say that there is a possibility in the future of getting them up to 250 feet a minute; but the experts in elevator practice tell me that there is no hope of an alternating current elevator which will do for one of your sixteen or twenty story buildings

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in the City of New York, and that is the service the central station company must supply.

In the table on page 846, where there is given a list of the things that you have to use with alternating currents only and with alternating and direct current, it seems to me the comparison is not quite fair. It would appear that in a large city, as I have stated in my paper, it is necessary, in order to cover the entire city, on account of its extensive area, to use a high voltage —a higher voltage than would be admissible for ordinary distribution; and if that is the case, you will require more apparatus than is specified under the heading of alternating current only. I have just roughed out here a little table which shows that as against rotary converters, you have primary mains, transformers and housing switchboards and a double system of distributing circuits, so that you have quite as much apparatus in order to fill the same specifications for general service with the alternating current in a large city—and I am not speaking of a small city—as you do with the direct-current.

The question of storage-battery has been brought up by Mr. Scott, and in his paper he states that the storage-battery may be used in substantially the same way with alternating current that it is usually used with the direct-current system, except that the converter is between the battery and the service. I do not think that is quite so, because, as I have said in my paper, the great value of a storage battery is in its action as the watchdog of the company's service; its liability to jump into the breach without any notice whatsoever. It must always be there ready to do its work. In order to accomplish this with the alternating current, and by means of a rotary converter, you must keep the rotary converter running twenty-four hours a day in order to be able to discharge the battery into the alternating current system, and further than that, if you wish to discharge the maximum capacity of the battery—and that is what we buy batteries for; we do not buy them to discharge over a load four or five hours wide, but over a peak—if you are going to discharge it over a peak, your rotary that Mr. Scott speaks about must be as large in capacity as your storage-battery, which, of course, means that the investment will be something enormous.

In summing up, I would simply say that there is an old proverb that "the proof of the pudding is in the eating," and if you will glance over the United States you will find that the successful companies, those that have grown to large proportions and have paid dividends, are those that have operated the direct current in the downtown districts, and it seems to me that that is the best argument that anybody could offer in favor of using the direct current in that portion of the city.

Mr. Arthur Williams:—In addition to the larger cost required for wiring for the alternating current arc lamp, suggested by Mr. Ferguson, it might be mentioned that tests made under

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acceptable authority have indicated that the alter
is not as efficient, in useful light giving, as the
lamp.

There is a very unexpected statement also
in regard to the Nernst lamp—to the effect
are to be obtained only from the use of the
I think the greatest development of the Ne
man, has been entirely with the direct-cu
efficiency at least equal, in other respects t
ciency obtained on the alternating current lin
inghouse lamp made in this country. The
installation in New York was made in an est
owner of which was demonstrated the superi
quality of the light given by the Nernst lamp b
of a Westinghouse Nernst lamp to and its supply fro
current circuit.

It occurs to me, in addition to what Mr. Ferguson has said
the storage battery supplied by an alternating current
used as a floating regulator on the system. Then, t
we should consider the great value of the storage-batter
mobiling. Apart from the fad of racing and touring
which are mere pastimes, the future of automobiling
edly lies with the development of a suitable electrical
Already this service is becoming of great commercial im
in the larger cities.

The importance of elevator service to the large supply
panies cannot be overestimated. In New York City there are
about thirty thousand horse-power in motors applied to electric
elevators. An elevator in an apartment house—a single el
only raises the character of the house, but very largely
the lighting revenue of the supplying company. The tend
in putting in electric elevators is to wire the building throughout
for electric light, and to add two or three floors, wh
equipped for electric light, become new territory for t
company. The electric elevator also is oftentimes a deciding
factor when the question of isolated plant competition is in-
volved.

Compared with the direct-current elevator the first cost of the
alternating current elevator is higher: the accelerating current is
from two to three times as great; the speed is limited to a maxi-
mum of about 150 feet a minute; it takes a great deal of time to
acquire speed—sometimes the car will pass the second floor before
reaching full speed; it lacks the safety feature of the solenoid
brake; it does not stop with the same precision; it is very noisy,
and the operating cost is probably double.

Thus I have given eight points of inferiority; to my regret,
because our interests would be glad to have and have long hoped
to find an alternating current elevator in every respect equal to
that of the direct current.

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A —Doubtless in this discussion Mr. Scott will be ook after himself, but there are two matters I wish h appear to me not altogether detrimental to the ting current. One is the matter of electric ele- fully satisfied in my own mind that electric lves are the thing, and I do not see why a hy- erated by a pump driven from an alternating t a pretty good thing in a way.

rotary converter which Mr. Scott speaks of as tion, I do not see that it is an added complica- good reason that the use of storage batteries he use of a "booster," even when the current is not know of any place or any instance except in where a battery can be floated directly across the n current and give it out at a constant potential would do for lighting. To do that we would have a battery absolutely no internal resistance, and it appears to me that ry converter would be merely a substitution for the nd, aside from the instability that might be created, I the rotary that would be no objection.

ENT STEINMETZ:—Regarding the much-mooted question ating and continuous current distribution, I desire to r words. Whatever I say, however, applies only to populated districts, because, in sparsely settled districts, utlying suburbs of large cities and the small cities, the ison becomes meaningless, since the continuous current is uded to begin with, and only alternating current can be used. Regarding the question of the arc lamp brought up, the sup- sed uperiority of the continuous current arc in efficiency has ry severely challenged in the last few years, and I believe , from the point of view of illumination. While the total flux of light of the continuous current arc is greater than that of an alternating enclosed arc—I mean in either case of equal consumption—the distribution of the light of the alternating arc is such that with the same power consumed in the arc and the same distance between the arc lamps the minimum intensity of illumination midway between the arc lamps is higher than with the continuous current arc, although the maximum intensity is considerably lower. What determines the usefulness of a lighting system is not the maximum but the minimum intensity of illumination, and in addition thereto the more uniform the intensity is throughout the illuminated area the better is the illuminant.

Coming to the matter of the comparison of alternating and continuous current in densely populated districts, here it is true the alternating current system appears the simpler, requiring no intermediary converting apparatus, while the continuous current system requires a rotary converter where the power is supplied from a large central station system. This apparently is a disad-

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vantage of continuous current distribution, since the problem of successful and proper engineering is primarily to reduce the number of complications to the least amount. At the same time, where complications are unavoidable, it is desirable to concentrate the complications in the station and sub-station; that is, to confine them to as few points as possible where the apparatus and the system can be properly taken care of. Now, what I desire to state is, that whatever additional complication is introduced in the continuous current system by the rotary converter is more than made up by the complication and the difficulties incident to the alternating system at the place where they cannot be controlled *i. e.*, in the house-wiring and secondary distribution.

The supply wiring and installation in the continuous current system is as simple as possible—as simple as gas or water supply. All that is necessary is from the mains or from the station to maintain the resistance below a certain value in correspondence to the load; that is, to know the load or approximate load, and then know the length of conductor, and therefrom the size of the conductor, and any wireman can easily learn that without any special intelligence. Different it is with the alternating current system. Here it is not sufficient to know simply the length and size of conductor, but in addition, you must not run the conductor through an iron pipe; you must not run conductors beyond a certain size, or you get an additional drop of voltage by self induction; you must not run the conductor and the return conductor too far apart; you must not run them close along an iron beam or through a hole in an iron beam; in short, you must not do a number of things which are harmless in a continuous current installation, and while all this is self-evident to an engineer understanding alternating currents, it is utterly hopeless to expect a wireman to understand it, and if a wireman has intelligence and capacity enough to learn it, then he will not stay a wireman very long, but will aspire to a higher sphere.

This is what I consider the most serious objection to the low tension alternating current distribution of large magnitude, and this additional complication, the necessity of care and attention, I consider as more than compensating for the absence of the complication of the rotary converter which, after all, is not so very serious.

Mr. Douglass Burnett:—A previous speaker has suggested the desirability of employing hydraulic elevators driven by alternating current motors I think that this suggestion may be dismissed as the electric motor driven type of hydraulic elevator has already proven itself impracticable for any service except the most intermittent. There are probably not more than half a dozen such machines in New York in business or apartment buildings, and we know of two which were replaced owing to the high cost of operation. In practice they are used chiefly for office build-

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ings employing central station electric service at night and steam-driven hydraulic elevators in the day time. The comparison may be stated on the basis of current consumption, which would be, for standard direct-driven electric elevators from two to four kilowatt hours per car mile; and for motor-driven hydraulic elevators from three to nine kilowatt hours per car mile. The figures apply to direct current apparatus and could be no less with alternating current machines.

Mr. Louis A. Ferguson:—I would just like to correct an impression in regard to the matter of rotary converters in connection with the storage-battery. The point that I wished to make was not an objection to using a rotary converter for the purpose of charging a storage battery for an alternating current system, although a booster would still be required, but to show that if the rotary converter were used in discharging the storage-battery for the purpose for which the storage-battery is ordinarily employed in direct-current systems, it would be necessary that the rotary converter should be as large in capacity as the storage battery would be at its one-hour rate of discharge.

I would also like to say for the gentleman who spoke that the direct current companies all over the country, or at least the companies operating direct current either in a portion or in their entire system, are keeping the batteries floating on the system, and do so by means of end cells which keep the potential of the battery the same as the potential of the system at all times.

A Member:—I would like to ask Mr. Ferguson how he charges the battery and the end cells.

Mr. Ferguson:—The battery may either be charged by a booster or directly from generators, or by the rotary converter and booster from an alternating current system.

Mr. Frederick V. Henshaw:—The question we are discussing this evening is as to the best methods of distributing power for large cities or small cities, for that matter, and the primary object is to secure the business of the city and secure it all, and distribute the power as cheaply as possible.

In examining various central station plants in this country a curious thing will be noticed. There are some cities where the central station has practically all the business; where you have to hunt around to find an isolated plant. There are other cities where practically every large building has its isolated plant. Mr. Ferguson has pointed out that in Chicago the electric elevator business is twelve and a half per cent. of the total, and that the electric elevator, which, off-hand, seems a small unit, will, if we examine into it, I think, turn out to be a very large unit, because if you are going to supply a large office building from a central station, one of the things you have to do is to supply it with electric power for its elevators unless it has hydraulic elevators.

As far as the electric elevator goes, there is no difficulty in making a direct current elevator motor which will start in four

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or five seconds from rest, and accelerate to full speed without taking any more current than the normal full load running current. This, there does not seem to be any present prospect of accomplishing with alternating current motors.

Another point that occurs to one, in connection with this difference between the amount of business secured by central stations, is that the city where the central station supplies nearly all the energy used in electric lighting and power would seem on the face of it to have the best system, but when we look into it we do not find that they have this ideal single alternating current distribution. The most marked instances, I think, are Chicago, Boston and Providence. Every one of them distribute their power by means of the direct current. That, of course, is not at all a conclusive argument, but it is one which is drawn from practice, and is apparently an indication of the desirability of direct current for power distribution.

Mr. John W. Lieb, Jr.:—Mr. President and gentlemen: From the drift of the remarks this evening, we seem to be in full sail on the sea of the old discussion of alternating current versus direct current distribution. I think that if the members whose opinions favor one side or the other of this problem, will look at it in all its phases and state the pros and cons with entire frankness, the result will be the clearing away of a good many misconceptions, and perhaps the final conclusion will admit the lack of universality of either system, and that it would be hazardous, indeed, to undertake a pronouncement in favor of either on purely general lines. The local conditions will have to be most carefully considered in each case before deciding which system is to be preferred.

I do not wish, in this discussion, to say much on one side of the question or the other, but the argument has been developed rather along the lines of problems of large cities with very dense and important industrial centres, than of smaller cities. It is unquestionably true that, in these large cities, with dense industrial and business centres, the isolated plant is one of the most important and serious problems with which the central station manager is concerned, and it is also true that the electric elevator is the key to the acquisition of a strong position in meeting their competition. While elevator service, in itself, may not seem to be an important source of revenue, the satisfactory and economical operating of electric elevators is of great importance in meeting and overcoming isolated plant competition.

I will just add one word as a parting statement. Mr. Scott has drawn a very interesting picture of the recent electrical development in Greater New York, and he states it demonstrates the various problems on a magnificent scale. He might have added just a few words to complete the picture he has drawn. He is depicting the conditions in greater New York, and he goes on to tell us that it is notable that all of this varied service

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is to be supplied from alternating current generators. I think he might add, in conclusion, that almost all of the distribution is by direct current.

MR. ARTHUR WILLIAMS :—May I ask just one question further in regard to the future? I think it is unquestionably true that the great future power development will be on the lines of direct application of motors to machines; for instance, to printing presses, to lathes, and to machines of all sorts, as well as to elevators, all of which require minute and flexible regulation, and I would ask Mr. Scott, in answering the inquiries of the evening, to include a statement as to the prospect of getting good regulation for alternating motors applied to that class of work, and how the result in his judgment will be accomplished.

THE PRESIDENT :—If there is no further discussion desired I shall give the floor to the authors of papers to conclude the evening, and I call upon Mr. Ferguson to make some closing remarks on his paper.

MR. FERGUSON :—Mr. President and gentlemen, I don't think I need to say anything more than I have said; I have talked a good deal already this evening.

THE PRESIDENT: Mr. Stott, I call upon you.

MR. STOTT :—There has been no discussion on my paper, and therefore I have nothing to say.

THE PRESIDENT: Gentlemen, I believe we have said so much on the mooted question of alternating versus continuous current that we have not discussed several of the papers. These papers supplied us with a number of important and valuable facts while the other papers dealt more or less with practical experience and with theories regarding which discussion was feasible ; so, naturally, the discussion has drifted into certain lines. I call upon Mr. Buck.

MR. BUCK :—My position is very much that of Mr. Stott's; my paper has not been discussed, and therefore I have nothing to say.

THE PRESIDENT :—Mr. Scott, I am sure, has something to say.

MR. SCOTT :—Mr. Chairman, when I received the papers for this evening I thought that mine was rather out of line as it simply contained a few generalities, while others had dealt with particular points, and had contributed something of interest and value; but it seems that the generalities have been rather popular to-night.

The paper is a general presentation of the subject on broad lines and it seems to me that the burden of proof is legitimately placed upon the advocates of the direct current. We start with alternating current; we then ask, are there good or sufficient reasons for transforming to direct current, and the direct current people have undertaken to defend their cause, and they have done it well.

I would be the last one to assert that the alternating current can

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in all respects equal the direct current for everything. I do not wish to take the position of a partisan, but on general grounds to present the two sides of the case. It should not be concluded because direct current has been used longer, or is used in a good many places that we should therefore decide it should always be used in other cases without reviewing the ground. The direct current advocates should show good reason for the faith which they have, and this they have been doing this evening.

I was quite interested in the curves which one gentlemen presented. The alternating current motor was shown with rather meagre lines. The curves were given with no particular reference to specifications as to the kind of motors referred to or the kind of service to which they are suited or the regulating devices which accompany them. We must take the curves just as they are.

At a meeting of the INSTITUTE a short time ago great stress was laid upon one feature of the alternating current motor which was not mentioned in connection with the curves this evening, namely, "the enormous starting current." This important feature of the other discussion was hardly visible this evening. But, taking the curves just as they were presented we have the rather remarkable result that the starting current of the direct current motor is twelve times the full load current for the series motor and eighteen times for the shunt motor. Taking the curves on their face a direct current motor takes eighteen times full load current as its starting current. That beats anything I ever heard alleged about even an alternating current motor. This illustrates my point that some of the off-hand assertions about the alternating current motor may be just as legitimate as my method of reading the curves of the direct current motor.

The matter of variable speed in the alternating current motor is a thing which the direct current people don't seem to understand and the alternating current people have hard work to get. As a matter of fact, however, the alternating current motor is making its way. We might conclude from some things that are said about it that it is something that is not in use and never will be. As a matter of fact, however, it is very widely used in many factories and many industrial establishments as well as in general service. You cannot do everything with the induction motor that you can with the direct current motor, but there are lots of things that you can do with it that you cannot do with the direct current motor. Each has its own characteristics. After careful consideration of the characteristics of the induction motor it has been selected for industrial establishments and when some speed change is necessary this has been provided in the motor or external means of changing the speed has been provided while the motors run at constant speed. In the operation of machine tools, for example, a belt between the motor and the tool with cone pulleys gives a much-to-be desired flexible connection between the motor

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and the machine, and devices are arranged for readily shifting the belt. I give this as a single means which is in satisfactory use for accomplishing some of the speed changes.

With regard to elevators, one would think that the alternating current motor could never get an elevator up. As a matter of fact, there are hundreds of elevators which are running by alternating current motors, and have been running by alternating current motors, some of them for several years.

We must remember that very much of the past experience with alternating current work has been on a small scale; motors have been put on generators which were of comparatively small size and which were not comparable to the large units which would be installed for a large plant. A ten or twenty horse-power motor will be, of course, relatively much larger on a fifty or one hundred horse-power generator than it would on a system having a capacity of thousands of horse-power, and that is such a system as would be installed in a large city. I must confess, though, that elevator work is getting to be something enormous when it must be estimated on "car miles." But sixteen-story buildings do not exist except in a few of the larger cities; in the cities of medium size elevator work of that kind is not the rule.

The Nernst lamp and its use with regard to a direct current has been referred to. The Nernst Lamp Company is a separate company, distinct from that with which I am connected, and I am not fully versed in the work they are doing. I am rather surprised to know that they put the lamps on any direct current circuits, and I do not know the place or the circumstances. However, Mr. Wurts, the Manager of the Company, who read a paper before the INSTITUTE not long ago, assured me he did not consider the lamp suitable at present for direct current circuits, and that they do not desire to supply lamps for those circuits.

Another point with regard to elevators I wish to speak of. A gentleman who is closely identified with direct current work, in talking over the elevator situation with me a short time ago, brought out a point which rather surprised me. He said, to change his words a little, you are not complicated enough; you have not got enough stuff along with the motor. We take a direct current motor to run an elevator and we expect all sorts of controllers and extraneous devices, and all kinds of magnets and rheostats added to it, but with an alternating current motor everybody thinks that there must be nothing at all; it must be ideal; and for that reason he thought that the alternating current motor had not had its full justice because it had not all of these regulating devices and compensating devices, and so on, that went with the full-fledged direct current elevator motor.

It has been said that the direct current motor is the thing and the only thing to run elevators. A comparison which may not hold good in all cases, but it may in some cases, would

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be this: If direct current is required at an elevator, then put in a little induction motor running a direct current motor to furnish that power. If the total amount of power required for elevators is small, and the reason for getting direct current is to supply those elevators, put in a little plant for supplying that small amount of power, and not put in rotary converters for supplying all the incandescent and arc lighting and other classes of motors which would be indifferent to the kind of current. If five per cent. or ten per cent. of the power is in the form of elevators which would require the special direct current, convert for that and not for everything.

A MEMBER:—Supposing the elevator work is eighty per cent.?

MR. SCOTT:—Supposing it is one hundred per cent., then we do something else.

A MEMBER:—How about the complication of apparatus in that case?

MR. SCOTT:—The complication of apparatus? Why you have got so much with the direct current motor anyhow, that a little in addition may not amount to anything. The little motor generator for supplying ten-horse power of direct current would be simple compared with going back and putting in a rotary converter sub-station for converting several hundred horse power, the rest of it to be used for other kinds of work.

The direct current wiring has been pointed out as a very simple thing, and the alternating current wiring a very difficult thing. Not long ago, up at the Pan-American Exposition, I had the pleasure of looking with wonder at some charts which our friend Mr. Mailloux had made of a large building, showing direct current wiring, and I should say that it would take more than an ordinary engineer to do work of that kind.

A MEMBER:—If it was an alternating current it would be a great deal worse.

MR. SCOTT:—It does take intelligent work, but my point is, that it takes an expert to lay out direct current wiring on a large scale.

A friend near me said a little while ago that this reminded him of the old days, when the subject of the alternating current versus the direct current was the red flag that would start everybody to moving. In those days there was one thing which was mentioned which the direct current friends brought up first, last and all the time, but which I do not recall, has been mentioned here this evening, and that is transformer losses. The field of battle has changed. The alternating current since those old days has made a rather startling change, and as I said in my first paragraph, it is no longer a question of direct versus alternating currents, but is a question of whether the alternating current shall do the whole thing or whether the direct current shall have a little corner left; whether the direct current will be able to

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hold the place it now has, or whether it will at some time have to give that up too.

THE PRESIDENT:—Gentlemen, the next paper was by Mr. Barstow. I call upon Mr. Barstow to close his discussion.

MR. BARSTOW:—There are just two points I would like to emphasize. One, as Mr. Ferguson has already explained, is the serious objection to the use of storage batteries for supply of alternating current; in fact, the idea is entirely impracticable. The second point the President brought out in relation to the use of transformers on the premises of the customers. This condition is even more complicated than the use of the sub-station with rotary transformer, because the company, in the latter case, has the transforming apparatus under special care, while in the former case it is distributed throughout the city on property not its own and beyond its control, where it cannot be watched and cannot be taken care of.

The remark that Mr. Scott made, that the burden of proof was on the direct current, I think entirely depends as to which end you view it from. If you are going to generate current and then be satisfied at its mere generation, that is one thing; if you are going to sell the current before you are satisfied, that is another. You are generating current to sell. If you generate alternating current and it cannot be purchased by the customer, what is the use of generating it? You should look at the whole question from the customer's standpoint. Those devices which are the most useful to him on the most useful system, you have got to supply in order to pay for the generating of the current; so that it is not a question as to whether the current shall be generated direct or shall be generated alternating, but as to what class of current shall be finally distributed. Mr. Scott also remarked in regard to the motors and devices for elevator work being complicated on direct current. As the cost of the motor, etc., is about the same, whether alternating or direct current is used, it means the customer gets more for his money if he uses direct current.

THE PRESIDENT:—Gentlemen, the next two papers were by Mr. Emmett and Mr. Robb. Since the authors of these papers are not present, we must leave it to them to conclude the discussion in writing. I may add, however, that both of these papers deal either exclusively or largely with alternating current distribution showing means adapted thereto, and neither of the two papers has been attacked in the discussion. This appears to me more than anything else to show that the alternating current is by no means at all yet hopelessly lost in inferiority. All the discussion we have had here about continuous current, or alternating current, refers to one particular phase only, although that place is their most important application, the supply of large cities and densely populated districts, but we all agree that in small cities and outlying districts of large cities, the alternating current reigns supreme.

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The last paper was the paper by Mr. Torchio, and I call upon him to conclude.

MR. PHILIPPO TORCHIO:—I would just add, in connection with my paper, that in the application of electricity to factories, the direct current may be preferable for certain classes of work, and I should think that in such cases the five hundred volt, three-wire system is considerably more adapted than the two hundred and twenty volt system as usually adopted now. I think that the trend of engineers is toward the adoption of higher voltages whenever it is feasible, and especially in large factories, where the motor load constitutes a large percentage of the total connected load.

THE PRESIDENT.—Gentlemen, we are through with the work of this evening, and I believe, if nobody else desires to make any remarks, a motion to adjourn will be in order. I thank you for your very generous participation in the discussion.

THE PRESIDENT:—Gentlemen. The topic selected for the next meeting is "Methods of Illumination." It will comprise all appertaining to electric illumination, the character of different lamps or illuminants, the intensity, distribution of light, color of light, etc.; also the character of the supply system required for their successful operation, etc. Contributions in writing for this discussion in the form of short papers are very welcome, and should be handed in to the Secretary, or to the Committee on Papers, on or before December 6th.

[ADJOURNED.]

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Discussion in Chicago.

Mr. R. H. Pierce:—I have here copies of Mr. Ferguson's paper, and also copies of a paper by Mr. Stott. Attached to Mr. Stott's paper are also several other papers. There is hardly time this evening to read all of these papers and go into the discussion of them, but I would like to leave the conduct of the meeting in your hands, and after Mr. Ferguson's paper has been read, I hope anyone who has anything to offer or to ask regarding the other papers will take part in the discussion of them.

The first paper, by Mr. Ferguson, is the main one of the evening. It is entitled "Distribution of Electrical Energy in Large Cities." This paper is the result of Mr. Ferguson's many years experience in Chicago, and those of us who know how well he has solved the problem here, appreciate the value of a paper from him on the subject. This paper will be read by Mr. Junkersfeld, of the Chicago Edison Company.

[The paper printed on page 813 was here read.]

Mr. Pierce:—I am sorry that I am not acquainted with each and every one of the gentlemen here this evening, in order that I might call upon the different ones to take part in the discussion of this very interesting paper, but I hope we shall have a number of volunteers.

This problem of the distribution of electricity in a large city is really not only a problem of distribution but it involves the problem of the most economical generation and transmission of electricity, because in a city of fifty-eight (58) square miles it is not a question altogether of distribution, but large amounts of energy have to be transmitted from considerable distances, and in selecting the system to be used, we have to consider, as I have said, both the economy of generation and transmission as well as distribution. It is clear from Mr. Ferguson's paper that his solution of the matter is that we should use a three-phase alternating system for transmission and that in the heart of a large city, at the present state of the art, we should use a direct current 220-volt three-wire system, the current of the system being generated A. C. or D. C., in accordance with the location of the generating plant, this of course being determined, as it is in this city, by the possibility of securing the location where we can get free water and coal at the minimum cost.

While Mr. Ferguson's conclusions are clearly the same that have been arrived at by many others, as shown by the practice of to-day, nevertheless, the position which he has taken in this paper has been combatted in years past and, in fact, there has been a discussion amounting almost to a quarrel in almost every meeting of any electric lighting association at which I have been present in the last ten years. So it is very probable that there may be some here to-night who may not agree with Mr. Fer.

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guson's solution of the problem, and if there is any one who has such views I should be very glad to hear from him.

MR. JUNKERSFELD:—It was with some hesitancy that I consented to read Mr. Ferguson's paper this evening, and inasmuch as he is reading the paper in New York to-night it will be their gain and our loss. On his return to the city I am sure he will feel pleased to hear that some opinions had been expressed on his solution of the question, at any rate.

MR. LYMAN:—This very complete paper of Mr. Ferguson's on distribution is certainly timely. We are all much interested in this subject. The tendency at the present time to consolidation of industrial lines is especially true of the electric lighting and power plants. As the development of controlling apparatus for the distribution of power has advanced we have been called upon to plan for a very great increase, not only in the power controlled, but in the district to be covered.

I think this paper brings out forcibly how thoroughly and well Mr. Ferguson and his engineers have developed from a number of small plants distributed throughout a large part of Cook County, one great system, delivering power to distances of eight or ten miles from the generating station with an efficiency of approximately 80 per cent., and maintaining a regulation that gives perfect lighting, and meets the demands also for the various kinds of power that are called for.

The Chicago Edison Company, in starting with the development of this extensive distribution system, began with a very large direct current system in the centre of Chicago, and I think that partly accounts for the larger proportion of the total power at the present time generated, being direct current rather than alternating. There is a district of some fifty or sixty square miles that is now being covered with 60-cycle alternating current, furnishing light and power. This alternating power has grown very rapidly, and I shall expect to see in two or three years' time the percentage of power used very much increased. The induction motors are coming into use very rapidly, and the advantages of alternating current for delivering over wide areas are, in general, far superior to direct-current, while it has a disadvantage at the present time in the case of elevator work. I shall not be at all surprised to see, within a short time, the induction motor applied to elevator work as successfully as it is to all the lines of power using constant speed.

There is one method of distributing power in which the Chicago Edison Company have been one of the pioneers, that I would like to call your attention to, and that is three-phase four-wire distribution. Power can be transmitted by this system at a given standard transformer voltage, with one-third the copper, or, the copper being the same, with one-third the loss that is required for single-phase transmission. For instance, by the use of the four-wire, three-phase system, using 4,100 or 4,000 volts, three

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phase, and 2,300 volts from the fourth wire to either one of the outside wires, so that standard transformers can be used, the power can be transmitted with one-third the loss, or a given loss with one-third the copper that it can be, single-phase, so that by using 2,300-volt transformers, for standard apparatus, with the three-phase four-wire distribution, lighting and power can be easily taken care of, from the power house five to eight miles away, and I have in mind a number of similar plants where this system is being installed,to take care of a number of towns located four or five miles from each other.

This part of the distribution system of the Chicago Edison Company, which is taken care of with the alternating current, represents a very good system for comparatively small towns—towns of five to ten, or even fifteen thousand inhabitants. One of the things that every lighting company at the present time is anxious to do is to put on a day power load, and this is being done to a great extent by the small lighting companies in small towns, with the 60-cycle, three-phase distribution, and especially where the distances are considerable, the four-wire three-phase system using 5,000 volts, allows them to go out after power that is perhaps some little distance away and to get a very paying day load.

MR. PIERCE:—We have this evening, in addition to Mr. Ferguson's paper, five other papers, which are all included in this second pamphlet, and inasmuch as they are all on this same subject, "The Distribution of Electrical Energy," I will read them by title, in the hope that they may call forth discussion, as some of them take the other side of the question ; that is to say, some of the papers seem to favor the use of alternating current where the practice shown in Mr. Ferguson's paper seems to favor the use of direct current. The papers are as follows :

First.—" Locating Faults in Underground Distribution Systems," by Henry G. Stott.

This paper simply describes a testing device for cables, which consists of grounding one side of a small generator and attaching the other to the cable, the current coming back through the ground and being an interrupted current of about 10 amperes. A series of pulsations are thus sent into this cable, and then the one who is testing walks along the cable with a galvanometer. Wherever pulsations are taking place in the cable they cause a swing on the galvanometer, and when the galvanometer passes where the trouble is located, these vibrations cease.

In about 1887 I expected to be connected with an operating company, and anticipating the troubles which I might have, as I had already worked on an underground system, and located faults with a pick and shovel, I experimented with a scheme which amounted to this same thing, except that instead of using a galvanometer I had a coil connected to a telephone. I would hold this to the cable, and when I got beyond the point where the

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pulsating current was going through the cable, the vibrations would cease to be heard in the telephone. My idea at that time was that you could not only use this at manholes, but that you could walk along the street and locate the trouble by carrying this coil close to the ground. I never tried it on the street, but I have no doubt that when a cable is not shielded by an iron sheath, this thing could be worked out on the same principle as Mr. Stott's galvanometer, and by having a properly designed coil in walking along the street you can stop right over the point where the trouble is.

The advantage of this system is that it can be used on an alternating current system while the system is in operation, whereas the disadvantage of the galvanometer would be that it would give a big swing, even if the cable had no current on it from influence of adjacent cables.

The next paper is on the "Buffalo High-Tension Cable Distribution System," by Harold W. Buck.

This paper is really more a paper on transmission than distribution. It takes up more particularly the transmission at 22,000 and 11,000 volts, and apparently gives as the reasons for it that 22,000 volts is low enough for overhead use, and 11,000 is as much as they dare put under ground.

Mr. Buck also describes some of the apparatus used at the receiving end.

The next paper is on the "Alternating Current as a Factor in General Distribution for Light and Power," by Charles F. Scott.

This paper is described by the opening statement, which says that the present problem is not alternating versus direct current, but is alternating current only versus alternating current *and* direct current.

Mr. Ferguson's paper describes the problem as worked out by the use of alternating current and direct current. Mr. Scott, apparently, from his paper, would solve the problem by the use of alternating current. In order to balance the account between these two methods Mr. Scott introduces the use of the storage-battery in an alternating current station, having it connected to the direct current side of a rotary transformer. This looks to me a little like a forced balance. If any of the members have ever known of this being done I shall be very glad to hear what results have been obtained. For myself, I cannot see how it can be done without inserting regulating devices into the system, which would prevent the satisfactory use of the battery in the same manner that it is generally used in direct current, where it is allowed to float on the system. Mr. Scott states that when a new plant is being laid out, it is probable the cases are very rare in which it would not, on the whole, be practicable to utilize either alternating or direct current motors. While this is possibly true, it is also true in the case of distribution in large cities,—such

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as Mr. Ferguson describes—we seldom if ever, can lay out a complete new system. When a new plant is being laid out it always indicates growth and increase. There is always a large amount of machinery on hand, not only that owned by the central station, but that purchased by the consumers, and it comes down to a business proposition. It is desirable to use as much of the existing apparatus in the station as possible. It is also desirable to use as much of the existing apparatus in the way of motors, etc., of the consumer as possible. The consumer does not want to buy any more than is necessary, neither does the central station want to replace one type of motor with another. It is also desirable to have the consumer use a type of machine which can be purchased on the open market, and which can be used on any ordinary plant. The central station has to compete with the isolated plant. If a man has an isolated plant and direct current motors he wants to attach them on to the central station; and again, if the company furnishes only alternating current and furnishes the alternating current motors, at the present price of such motors and the present state of competition, the large number of men who are selling direct current motors will begin to try to get people to put in isolated plants and put those motors in. In other words, the motor men are against the central station, except where the central station does not attempt to sell motors, but to furnish current that can be used by any motor.

On page 848 it seems to me Mr. Scott has summed the thing up where he says: "Probably the most pertinent conclusion to be drawn from a discussion of this kind is that there is no ideal system, and no panacea plan which can be universally applied. Existing and local conditions, special requirements, and the relative importance of the various classes of service to be rendered, must all be taken into account in determining what will be adequate in an individual case."

The next paper is entitled "Notes on the Alternating Current System of Distribution," by W. S. Barstow.

Mr. Barstow is a pioneer in the application of alternating current transmission combined with direct current distribution. His paper carries with it great weight, and his conclusions on page 853, in regard to the points that are necessary to be overcome before the alternating system can replace the direct current system, in distribution in a large city, seem to represent the opinion of the average conservative man at the present time. I will read the statement, as it seems to me to be the gist of his paper:

"What is required to-day, however, if the alternating current besides retaining its field of transmission and scattered distribution where it is supreme, would enter the compact direct current field of distribution, is:

"First.—A standard type of motor which can be used for all

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classes of business demand and will meet the same commercial requirements as the present direct current motor.

"Second.—A universal system of supply which does not require transformers, etc., or anything outside of the meter itself, to be located on the premises of the customers.

"Third.—Some apparatus, which in connection with alternating current will take the place of the storage-battery supply on the direct current."

The last paper is entitled "Distribution by the Three-Phase System and the Operation of Single-Phase Circuits by it," by W. L. R. Emmet, who is universally conceded to be an authority on this subject.

Mr. Emmet's paper gives the reasons why he thinks the three-phase machine should replace the single-phase machine for all purposes, and is then taken up by a description of his method of three-phase distribution, particularly the three-phase four-wire system, where the three-phase machines are connected in "Y" with the fourth wire connected at the centre. This is the system that has been described in Mr. Ferguson's paper as being used in Chicago. I should be pleased if, in the course of discussion, someone would make some statement as to his experience regarding the regulation which is obtained on this system.

I will say for myself, that I have recently had occasion to take up the matter of alternating versus direct current in the down town distribution of a large city, and while I believe that at the present state of the art the direct current distribution is the best, I was also confronted with the proposition, in this particular case, that it was impractical to change over to the other system, even if the balance were in favor of the alternating, owing to the fact that we had a large number of direct current motors installed, and also owing to the fact that we had to keep the station running. In every one of these cases it is like the case of a school board who wanted to "build a new school house on the site of the old schoolhouse, and to use the old school-house until the new schoolhouse was completed." Even if no very radical changes are made in the method of distribution it becomes quite a problem to give good service and change over a plant, and that is one of the reasons why some of these papers show one system to be advantageous in a theoretical light and other papers show that men who have charge of operation have done something different.

Taking the papers as a whole, they represent fairly both sides of the controversy.

MR. A. OSTHOFF:—There is one little point in connection with the load diagram contained in the paper by Mr. Ferguson that is somewhat interesting as showing the part played by the battery in relation to the load factor. I had occasion to look over a load diagram of the Chicago Edison Company recently, and found that, assuming, as a definition of the load factor, the ratio of the average to the maximum, it came out about 37 per cent.,

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and then taking the battery into consideration the factor increased from 37 to something like 53 per cent., and then, considering the fact that the Chicago Edison Co. has installed 50 per cent. more battery since then it could be raised to 62 or 63 per cent. Possibly Mr. Carlton has some figures on that.

MR. CARLTON :—No, I have no figures. I did not know what the percentages were until Mr Osthoff gave them. The fact of cutting off the peak with a battery does very materially improve the load factor figuring it from the generated output.

MR. PIERCE :—Have you ever seen a case where the battery was used on an alternating system in the manner described by Mr. Scott?

MR. OSTHOFF :—Not exactly with that idea. I know there have been some cases where, in a case of emergency, the battery floated through the rotary and carried the alternating side of the system during a breakdown. I think that it was in Hartford about two years ago that this thing occurred, but I am not familiar with the details, and thus make the general statement.

MR. PIERCE :—That is really substantially the thing that is done in New York in the Pearl Street Station. They have a big battery, and it may be battery that is feeding alternating current, but whether or not that has ever been installed in connection with an A. C. distribution I do not know.

MR. OSTHOFF :—I do not think anything like that has ever been done.

MR. JUNKERSFELD :—Supplementing Mr. Lyman's remarks, and also those of the Chairman, I note that one reason advanced by Mr. Lyman as to why the large proportion of total power distributed at the present time by the Chicago Company is direct current, was because the direct current system was started in advance of the alternating. I think the commercial considerations that the Chairman particularly drew attention to were a very great factor in the more recent development of this large direct current distributing system.

Any lighting company to attain permanent success must have something to sell for which there is a market. The early development of direct current motors made possible a market for direct current that could profitably be supplied, as it meant a day load. In Fig. 3 Mr. Fergus n's paper shows the large percentage of total load that consists of general power and elevator work. The connected load in elevators alone is about 12½ per cent. of the total. It should be kept in mind that alternating current distribution is employed in all the outlying and suburban districts in Chicago, but that such K. W. H. output is a comparatively small percentage of total in the entire city.

The four-wire three-phase system of distribution, that is discussed in Mr. Emmet's paper was put into service in Chicago about one year ago, and has been found very satisfactory. One great advantage of such a system is that it may be installed and

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a very large investment in line work utilized. By that I mean that you can go into a city where the investment in line work is considerable, and you can start in a system of this kind with small change in the distribution system and slowly convert it.

In Mr. Stott's paper he describes a number of methods for locating faults. In this connection, I will say that some work has been done by the Chicago Edison Company recently along this line (the accuracy of which is even better than Mr. Stott mentions); and as the young man is here to-night who is largely responsible for that work perhaps he will tell us about it. I refer to Mr. Eastman.

MR. EASTMAN:—The method we used in locating faults was the Murray loop method. Mr. Stott states that the loop method of locating faults cannot be applied to cables larger than No. 0 B. & S. gauge. We have successfully applied the method in locating faults on cables of No. 00, and have made tests that show it could be used on cables of 500 circular mils and in very short lengths. In most of the instances where we have applied it we have obtained accuracy in locating faults within one per cent. It seems to me the whole success of this depends upon the method in which the test is made, and the adjustment of resistances used in making test.

Mr. Stott, in speaking of locating faults by the use of the loop system, says that the influence of the ground will enter in such a manner that the results will not be correct. But with the method of using it with the reverser end taking proper deflection both ways, this fault is practically eliminated.

PROF. WOODWORTH:—I came to this meeting simply to listen. I recognize that the problem which is presented to the people who are installing plants in large cities is a large one. The Chicago Edison Company, for instance, has probably before them the largest problem that is to be solved in the city of Chicago. All the new things that are going to be done in Chicago will probably come along that line, and I hope that Mr. Ferguson and his engineers have solved this in the right way. I would be sorry to think that they have been influenced by the commercial side of the small motors owned by their prospective customers. I hope that that has not been done, because there is no reason why the Chicago Edison Company cannot supplant all the plants in the city of Chicago. They should do it and it would be the best thing that could happen to the city of Chicago; and if we want Chicago to be smoke free that is one of the ways to do it. I am quite sure that they are at the present time giving a very satisfactory service, and am very much pleased to see the work and to hear this paper this evening.

In one of the papers that was not read this evening, Mr. Emmet's, I was quite surprised to see the statement in which he cuts out the two-phase machine. Let us take the problem that

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the Chicago Edison Company have on hand. There is no question at all but that they want the three phase. We will suppose we have a small plant—about 200 kilowatts. A man wants to put in a plant and his distributing area is small, or very scattered.

It would not pay to put in step-up transformers for a distance of four, five or six miles, and in that case he wants to put in a machine that is going to give satisfactory service. As Mr. Emmet explains, it will be economy for him to buy a multiphase machine; but he says, not the two-phase. Now, if we put in such a plant we will have to cut out what Mr. Emmet recommends, and that is, the engines to handle that plant. If that is the condition for that case I think every one who handles such a plant will find the two-phase plant fulfills that position much better than the three phase. My own personal experience has been that the two-phase machine is very much more easily balanced than the three phase with small loads, and when it comes to using such a service as we will usually have, about 80 per cent. light and 20 per cent. motors, with that condition it will require only two transformers for the motors in place of the three required if we use the three-phase system. Of course, the sizes won't make much difference, but so far as the value of the system is concerned, I cannot see why he cuts out the two-phase system, as there are places where it seems to me it is advantageous.

MR. LYMAN :—Referring to the question that has just been brought u , as to what advantage the three-phase generator has over the two-phase, I have seen rare instances where the two-phase generator had perhaps an advantage over the three, where the distribution was limited and where the power was to be used principally—almost entirely, perhaps—for lighting, and there were only two circuits, as the Professor has said, to balance, instead of three. There generally come, however, problems of power, and they are coming more and more with the old plants that are remodeled, and the new ones that are starting up in a new field that offer a very good day load ; also in extending transmission of power for lighting or for power work, a considerable distance from the station. Wherever either of these conditions come in the three-phase system meets the conditions better than the two phase. There is a saving of 25 per cent. in the expense of copper so far as the power is concerned, and if the power load is considerable, the lighting load can be simply taken and put all on one phase as the three-phase generator is capable of carrying 80 per cent. of full load three-phase; and one does not have to balance two-phases or three-phases if there is a moderate amount of power. All stations are coming to more use of pow r than in the past. So far as transformers are concerned in small motors of 10 or 15 H. P., two transformers are generally used for a motor. Wherever power is used in the buildings there are less cables, less wires, less wiring fixtures, less fuse boxes, and even the switches are three pole instead of four pole.

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I have known of a number of cases, in the laying out of plants, where a customer has been very sure at first that he wanted a two-phase machine, but, after a very careful study of the matter, decided that he would prefer a three-phase machine.

MR. PIERCE:—Do I understand, Mr. Lyman, that the three-phase machine will carry 80 per cent. of its rated load on one phase with the same heating it would have with the full load on three phases?

MR. LYMAN:—It carries 80 per cent. on two of its windings. If we take a single-phase current from a three-phase generator, by connecting with two of the connector rings we always get two of the three windings in series, although they are 120 degree instead of 180-degree phase displacement.

MR. PIERCE:—Would it carry 80 per cent. of its load with the *same heat limit?*

MR. LYMAN:—Yes; from 75 to 80 per cent. Some of our machines will carry not more than 75 per cent., but most of them will carry 80 per cent.

MR. PIERCE:—If this is a matter of experience, as to just what per cent. these machines will carry on one-phase, I would like to ask Mr. Lyman what his experience shows a two-phase machine would carry—what per cent. of its total load it would carry on one-phase with equal heating.

MR. LYMAN:—The heating in one coil on a two phase machine would be one-half of its rated load. In the two-phase machines the winding is made in two ways—one of them is a continuous winding and the other (which is adopted by the General Electric Company) consists of two independent windings.

MR. PIERCE:—When you speak of 75 or 80 per cent. on a three-phase machine, you refer to a machine with the "Y" connection, I presume?

MR. LYMAN:—Yes; that is our standard connection for generators, and you will notice that there is only one-third of the armature winding that is not active in that case.

MR. PIERCE:—So your comparison is between a "Y" connected three-phaser and a two-phaser with two independent windings.

MR. LYMAN:—I have no data on the two phase machine, but our tests show that the three-phase machines can be operated in that way.

If we take the four-wire "Y" connected, 4,000-volt, three-phase machine, my statement would not hold, but it is true of our standard 2,300-volt machine. Nor do I think it would hold good on a continuous winding with taps brought out. I think it might hold good on a delta winding, but am not positive about that. In that case there is one circuit in multiple with two circuits in series, and all the armature windings are active to a certain extent.

MR. PIERCE:—If you compare the continuous winding with

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the three taps—three-phase—with the same kind of connection, on two-phase, would not the two-phase carry more current—a bigger proportion of its rated load with the same heat limit than three-phase?

MR. LYMAN:—I do not know. I should not be surprised; but I do not know what it would do.

MR. JUNKERSFELD:—Does the question not resolve itself into this: If you take that single-phase current at 4,000 volts, you will use two-thirds of your winding approximately; you will be able to take out approximately two-thirds of the capacity, and you have all of the radiating surface to help you out. With the continuous winding on the two-phase machine, you would have practically one-half the copper in action while with the three-phase machine you would have only one third of the copper active that is carrying somewhere near normal current, and comparing the two continuous windings, the three-phase would carry a larger proportion. In other words, it depends usually upon the amount of winding you have active.

MR. LYMAN:—In the case of the continuous winding in the three-phase there is more than one-third of the winding that is active. All the winding is active to a certain extent, but there is twice as much current in one branch as there is in the other. They are unequally divided.

MR. DAMON:—To those of us who are familiar with the conditions in Chicago, Mr. Ferguson's paper has been of particular interest, and I am sure we all share an admiration of the results which have been accomplished by the Chicago Edison engineering organization. But when the rotary converter storage battery sub-station system of distribution is considered in general without the influence of local conditions, I am certain that most of us feel that this system is far from ideal.

Under the present condition of excessive cost of alternating current equipment the advantage of the alternating current motor will seldom justify the extra investment its installation entails, and this is the reason that at the present time I am a friend of the direct current motor, but competition will lower the price, and I believe that eventually the development and universal adoption of the alternating current motor will remove one of the present excuses for the rotary converter sub-station.

Our office has always been a friend of the storage battery, and we are glad to share with our accumulator friends the satisfaction in seeing its advantages fully realized and appreciated. The adaptability of the storage battery to the sub-station system of distribution goes a long way toward justifying this complicated arrangement. When we stop to consider, however, the high first cost, the inefficiency in operation and the inherent complication of the entire scheme, there are few of us willing to agree that the sub-station system is a logical engineering solution of the distribution problem.

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The rotary converter sub-station has been widely adopted for long-distance electric railroads, and it is in this class of service that the development of alternating current motors is sure to have its most marked effect. There seems to be nothing in any of the papers under discussion this evening on distribution for railroad work, and it is only because some of the papers refer to future developments that I take the liberty of introducing the subject.

It is in electric railroad, and in particular high speed electric railroad work, that the rotary converter sub-station system developes its most serious limitations. This system was originally adopted to cut down the investment in conductors, and to allow the concentration of generating machinery in large central stations. Sub-stations were at first placed about twelve miles apart, then ten, then eight, and as the size and number of trains are increasing it is found desirable to design some roads with a sub-station every six miles. With this arrangement the accelerating of passenger trains weighing, say, 60 tons, to a speed of sixty miles per hour in a period of sixty seconds, requires so much power that the first investment in sub-stations and conductors limits the commercial success of the proposition, while the moving of freight in large quantities is highly impracticable.

All requirements point to the necessity of developing the alternating current motor for railway work, and a study of the conditions indicates that the alternating current should be taken direct to the car and at a high tension in order to avoid a complicated inefficient and costly distributing system.

I thoroughly agree with Mr. Ferguson's opening and closing sentences, that we must look toward the future and must have a simple, universal system of generation and distribution. For this reason I am of the opinion that in course of time there will be developed apparatus which will do away with the necessity of the rotary converter, storage battery sub station system.

MR. FOSTER:—I came here simply to listen to the papers, but was too late, I find. I have been very much interested in some of the remarks, however.

I think Mr. Damon has hit the nail on the head, and that the alternating current is the system we are going to look forward to and get good results. I do not think the time is far off when we will see alternating current motors on street cars; in fact, I was talking with a gentleman not long since who is preparing his patent papers now on a device which I think is going to be a step in that direction, and we may see some results in that line.

MR. OSTHOFF:—I would like to ask Mr. Damon if he really believes this alternating current is going to be so universal as that it will be used on interurban city railway work?

MR. DAMON:—I will say that the present idea would be to use a high tension for interurban work and low tension for urban work, and when the cars reach the city lines to use the low ten-

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sion, direct on the motors without a transformer between the trolley and the motor.

MR. BALL:—That brings up the question of changing millions of dollars worth of work for the sake of an idea. In regard to the use of alternating current on street car work, of course it has been done in Europe; there are two or three systems there, I believe, but I think the matter was summed up in a discussion by Mr. Steinmetz sometime last spring (see TRANSACTIONS of March 22, 1901, p. 383). I cannot at this time bring out all the points he did there, but he pointed out very clearly in that discussion the different points to be overcome.

As to the matter of distribution systems, whether we should use alternating or direct current for general work, it is a question, according to my mind, of compromise. Of course, in Mr. Ferguson's paper, he has done the only thing that could be done, because he had such an extensive three-wire direct current system here.

There is no doubt that the generator in the station should be an alternating generator—possibly in some cases it could be a double current generator—and as Mr. Scott stated in his paper, I think it would be well to make as few transformations as possible and to use the alternating current for all incandescent lighting; and, in fact, everything except street railways and special motor service, such as elevators or variable speed motors, which, up to the present, have not given satisfactory service with the alternating current.

In the arc light system it is a question whether we should use 60-cycle alternating current, or whether we should use 25-cycle with synchronous motor and direct current arc machines. Personally I prefer the latter for two reasons: One is that the efficiency of the lamp is better as a light-giving mechanism, and the other is, that the percentage of the load required by the arc lights is generally so small that it would pay to use the 25-cycle system. As I said before, it is a question of compromise and conditions in the different problems we have to face.

MR. DAMON:—In regard to the efficiency of this distribution system, Mr. Ferguson gives the efficiency of pretty nearly 80 per cent. I suppose that includes the step-up transformers from the double current generators.

MR. JUNKERSFELD:—Yes, that includes the transformers. Eighty-two per cent. is the k. w. h. efficiency and not the maximum or k. w. or rated load efficiency. This figure will be considerably improved during the year as larger rotary converters and line voltage generators are put in service.

MR. CRAVATH:—Of course, the efficiency of any polyphase system of distribution at this time is dependent very largely on the size of the distribution. I happened to be looking into the figures of a large railway plant this summer—polyphase distribution—where the efficiency reached as high as 90 to 91 per cent., from

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the bus bars of the generator plant to the busbars of the sub-station In that case there were no step-up transformers. I had occasion recently to look into an interurban road, covering a good many miles into the country, having numerous sub-stations, where the efficiency reached was a little less than 20 per cent.

MR. PIERCE:—I agree with what Mr. Damon says, that we ought to build for the future, and I believe with him that anything that is complicated will have to pass away, but the problem, in a large city is, to a large extent, "making the punishment fit the crime," and in a problem which we just now have before us of putting in a 12,000 h. p. plant which is to furnish arc service, three-wire system, alternating lighting, and 500-volt power service, we have found it necessary and desirable to keep all of these varieties of service and *distribute* them substantially in the same manner in the future as we have in the past. There has been some criticism made of engineers who simply figure the cost of power on the bus bar, but after all, the nearer you get back to the coal pile the more you can save, and the best station is the one in which you produce kilowatts at the least cost, and then distribute so as to get, in the first place, reliability; in the second place, good regulation ; and, lastly, as good economy as possible. In the case which we have just had at hand we put in three-phase 25-cycle generators which will do for both the present and the future, and the nearest we got to anticipating an alternating distribution for down-town lighting was to put in three-conductor cables for feeders. The rest of it was the straight three-wire direct current system.

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[COMMUNICATED AFTER ADJOURNMENT BY D. W. ROPER.]

The statement of Mr. Stott in his paper read November 22 that "the loop test is not applicable to any conductor larger than No. 9 B & S. gauge, and therefore of no value for lighting and power purposes," is radically opposed to the experience of the writer, who has, for over three years, used a loop test with entire success on cables of 150,000 c.m. and 1,000,000 c.m. The connections used in making the test are shown in Fig. 1.

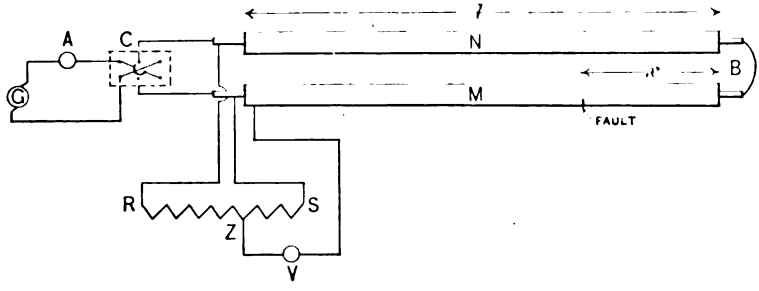

FIG. 1.

M. is the grounded conductor which is connected at its end to the good conductor N by means of the loop; B G is a direct current exciter; C is a reversing switch; R S is an auxiliary resistance; V is a Weston voltmeter with a 5-volt or a 15-volt scale. One terminal of the voltmeter is connected to the lead covering of the grounded cable.

A point Z is found on the resistance R S, so that the voltmeter, V, reads zero. Readings are then made of the voltages R Z and S Z. The above operations are then repeated with the switch, C, reversed.

Then if a = mean of two readings R Z,
b = " " " " S Z,
l = length of cable,
X = distance from end of cable to fault

$$X = \left(\frac{a-b}{ab}\right) l$$

The first attempt to make a loop test in the ordinary manner proved the impossibility of making any test of this nature which required the fault to carry any appreciable amount of current at a low voltage. The connections were then changed so that

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the conductors carried the testing current. The method was then tried on a feeder which had been installed, but was not in service. An artificial ground was made by opening a joint, and grounding one conductor with a wire. Then a test made in the day-time missed the actual location by about 3 or 4 per cent. A test made between 1 A.M. and 5 A.M., had an error within the errors of observation on the Weston voltmeter. But after a few nights' experience in testing at this hour, there was felt to be a very pressing need for a method that could be used in daylight. The scheme of reversing the testing current at the cable, and using the mean of the voltmeter readings was then tried, and several readings were taken to insure greater accuracy. As this method assumes the current in the ground return of the electric railways is the same for each set of readings, it is naturally not quite so accurate as a test made with no current in the ground return. But when the average of several readings is taken, the actual error as found in practice is still only a fraction of one per cent. For a time records were kept of the location of the faults as determined by test, and the actual location as found by the repair gang. A number of these records are given in the following table:

Length of Feeder.	Size of Feeder, C. M.	Location by Test.	Actual Location.	Error in Per cent.
5,805 ft.	1,000,000	492 ft.	488 ft.	.07
5,967 "	1,000,000	5,533 "	5,538 "	.08
4,672 "	150,000	314 "	202 "	.26
4,672 "	"	3,186 "	3,191 "	.11
4,372 "	"	40 "	12 "	.23

The locations of the grounds are measured from the end of the feeder.

At the time this table was compiled, the two tests on 1,000,000 c.m. cable which are given were the only ones that had been made. In one of them the total voltage on the cable was about seven volts, and the difference in the voltmeter readings on the auxiliary resistance with the current in the cable reversed was over two volts. This difference averages about 1.5 volts with a range from 0 to 2.5 volts, and is fairly constant during the several readings of any one test. The current used varies from 10 to 90 amperes, and depends on the length and size of the cable, and is selected of such a value as will give a large scale deflection on the Weston voltmeters available. These voltmeters have scales of 5, 15 and 150 volts.

No special apparatus whatever has been used in making these tests. The few switches required were found in the store-room. The testing laboratory furnished the instruments. One of the

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station exciters was used to supply the current. The exciter armature leads were tapped between the machine and the switchboard. A double throw-switch is inserted in the exciter field circuit and so connected that when the switch is in one position, the machine is self-excited in the ordinary manner; with the switch in the other position, the machine is separately excited from the other bus-bars, and the field circuit is led through a rheostat at the testing bench. For the auxiliary resistance we used two discarded field rheostats placed in series to secure a larger number of divisions. If the actual zero happens to be between two of the contacts on the rheostat dial, a little resistance is cut out of one of the rheostats by moving the handle until the zero point is on one of dial contacts.

The time required for taking the readings and figuring the results should not exceed twenty minutes. It is frequently necessary to break down the insulation at the fault by the application of high pressure, in the manner described by Mr. Stott. When the cable tester has been notified of a grounded cable, he is expected to make his connections, readings and calculations, and report on the location of the fault inside of an hour, unless there is a delay in the looping together of the ends of the feeder.

The method described is obviously of no value when the cable is entirely severed by the burn-out.

[COMMUNICATED AFTER ADJOURNMENT BY W. E. GOLDSBOROUGH.]

Supplementing the discussion upon Mr. Scott's paper I offer the following matter bearing upon the performance and efficiency of direct current and induction motors. The curves presented when studied in connection with the very interesting set of curves shown by Mr. Dunn will, I trust, throw additional light on the relative merits of these very necessary auxiliaries to the distribution of power by electricity.

If we turn to a consideration of the relative efficiency of transmission in the several systems which are used for the electrical distribution of power we find that when the same maximum difference of potential is maintained between wires, and the same weight of copper used in each case, the losses will be to one another as the following percentage values, the losses in the direct-current system being taken as 100:

Direct-current distribution, two wires	100
Single-phase current distribution, four wires	100
Two-phase distribution, four wires	100
Two-phase distribution, three wires (reckoning the voltage between lines and common returns)	72.8
Three-phase distribution, three wires (mesh connection)	75

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An equitable comparison of performance by motors necessitates the elimination, in so far as possible, of all outside considerations which affect the consistency of the conclusions arrived at. It is my purpose, then, to equate the results of tests upon motors, first, on the basis of a uniform maximum potential of 500 volts; second, on the basis of the same weight of copper being used in the lines, and make these two assumptions the basis of comparison between the currents taken by the different machines. In line with these assumptions take r as representing the resistance of the line copper, supposing it to be made into a single conductor extending over the distance between the points connected in the transmission; then four times r will equal the total resistance of the outgoing and returning transmission wires

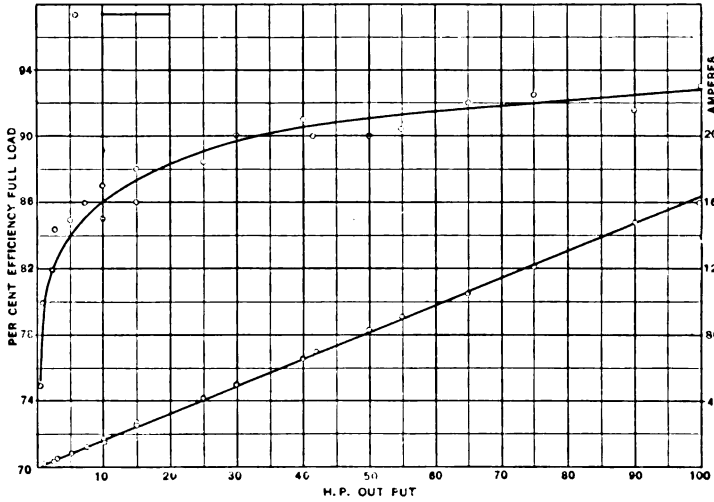

FIG. 1.—Efficiency and Current Consumption of Direct Current Motors.

when direct-current motors or single phase alternating current motors are used. Nine times r will equal the total resistance of the transmission lines for operating three-phase motors, since each of the three wires will have one-third the cross-section and three times the resistance of the initial single conductor; and, finally, sixteen times r will be the total resistance of the transmission wire when two-phase motors are used, since this transmission will necessitate having four lines, the cross-section of each of which will be one-fourth of that of the initial conductor, while the resistance of each will be four times that of the initial conductor. Therefore the losses in the several transmitting systems will be as follows, assuming the same amount of power to be transmitted in each case:

For d. c. and a. c. single phase

$$4\ r\ I_d^2 = (2\ I^d)^2\ r$$

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For a. c. three phase

$$9\ r\ I^2_3 = (3\ I_3\ )^2\ r$$

For a. c. two phase

$$16\ r\ I^2_2 = (4\ I_2)\ r$$

From which the equivalent current values are to one another as

$$2\ I_d : 3\ I_3 : 4\ I_2 \text{ or as } I_d : 1.5\ I_3 : 2\ I_2$$

Therefore in comparing the characteristics of direct-current and induction motors the current values must be multiplied by the following constants ;

The direct-currents by.....1
The single-phase a. c. currents by.....1
The two-phase a. c. currents by.....2
The three-phase a. c. currents by.....1½

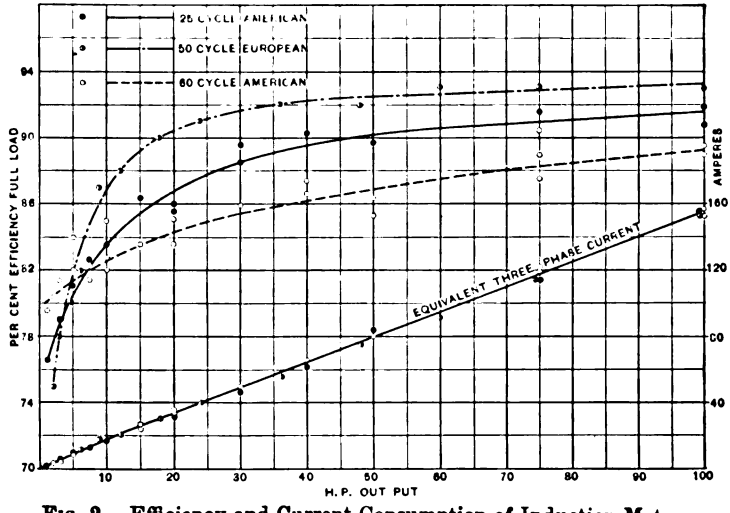

FIG. 2.—Efficiency and Current Consumption of Induction Motors.

This method, consequently, equates the currents in the ratio of the square roots of the line losses, and gives values that are equivalent to the tax for current which is imposed upon the transmitting system by the motors of each class.

To give point to the discussion, we will confine our attention to types which may be classed as moderate speed, constant potential motors. In doing this we eliminate all types known as slow-speed motors, whether they be for direct or alternate current working. It is desirable to do this, since the moderate speed ratings in all types have fortunately given rise to motors, the speeds of which, for given powers, are very nearly the same in each class.

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In Fig. 1 we have two curves shown. The upper one illustrates the variations which occur in the full-load efficiency of direct-current motors up to 100-horse power. This efficiency curve has been plotted from the results of tests made upon machines which are the output of three of the best American factories. The number of tests cited is indicated by the plotted points. It will be seen that the variation in the efficiency of standard moderate speed motors hardly exceeds 2 per cent. in any given size, which is a sufficient indication that manufacturers have finally arrived at practically a uniform standard in the design of direct-current motors. The lower curve shows the full-load line-currents taken by the several motors.

In Fig. 2 we have a similar set of curves applying to induction motors. Here, however, it is necessary for us to separate the

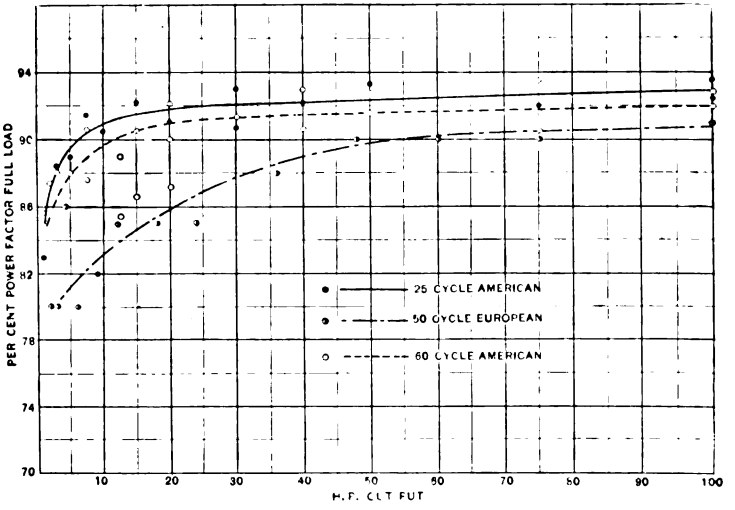

FIG. 3.—Full Load Power Factors of Induction Motors.

motors into three classes. Accordingly the dotted efficiency curve gives the average results of the performance of twenty-five cycle American induction motors, ranging in capacity from 5 to 100 horse power. The dot and dash efficiency curve gives similar results from American sixty-cycle motors. The full line efficiency curve, however, gives the results of tests made upon fifty-cycle European induction motors. From these curves it appears that in so far as American motors are concerned, standard construction gives rise to higher efficiency in low frequency machines than in high frequency machines. The European motors show uniformly a higher full load efficiency than the American motors. At first, this would seem to be a point of superiority. It is, however, a point to be debated, as by reference to Fig 3, it will be

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found that the power factors of these European motors at full load are considerably lower than the power factors of American motors at full load. The performance of standard induction motors clearly indicates that we can not have both high full load efficiency and high power factor, and the American engineer appears to have decided in favor of the latter rather than the former.

Fig. 4 shows the apparent efficiency of the three types of induction motor already referred to. Fig. 4 shows that the apparent efficiency of the twenty-five cycle American motors and the fifty-cycle European motors follows practically the same variations with change of capacity, although in the case of the former the power factor is relatively high, and in the latter the power factor is relatively low ; inverse relations existing between their efficiencies. The apparent efficiency of an induction motor is important. The capacity of prime movers is usually gauged

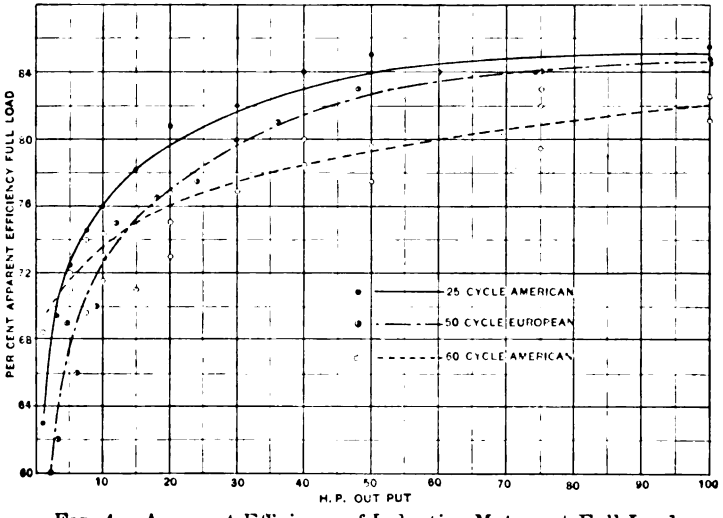

FIG. 4.—Apparent Efficiency of Induction Motors at Full Load.

by the actual power required to operate the motors. The capacity of electric generators supplying power to induction motors cannot, however, be rated in this way. Their capacity is fixed on the basis of the apparent watts taken by the motors instead of the real watts taken by the motors, since they are required to supply the necessary voltage as well as the necessary current. Their armatures must, therefore, be large enough to prevent the lagging currents in the system from causing overheating.

As, so far, only full load values have been discussed, it may be well to consider for a moment the variations that occur in the characteristics of high and low power factor machines for all conditions of load. Take, then, for example, the curves shown

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in Fig. 5. The full lines represent the performance of a two phase, 50-horse power Westinghouse induction motor, while the dotted lines represent the performance of a 50-horse power European motor made by the Allgemeine Company. The characteristics of the machines differ chiefly in the divergence which takes place between the efficiency and power factor curves. For general commercial purposes the American motor shows an improvement over the European motor in that it will affect the regulation of the system less both at light loads and high loads.

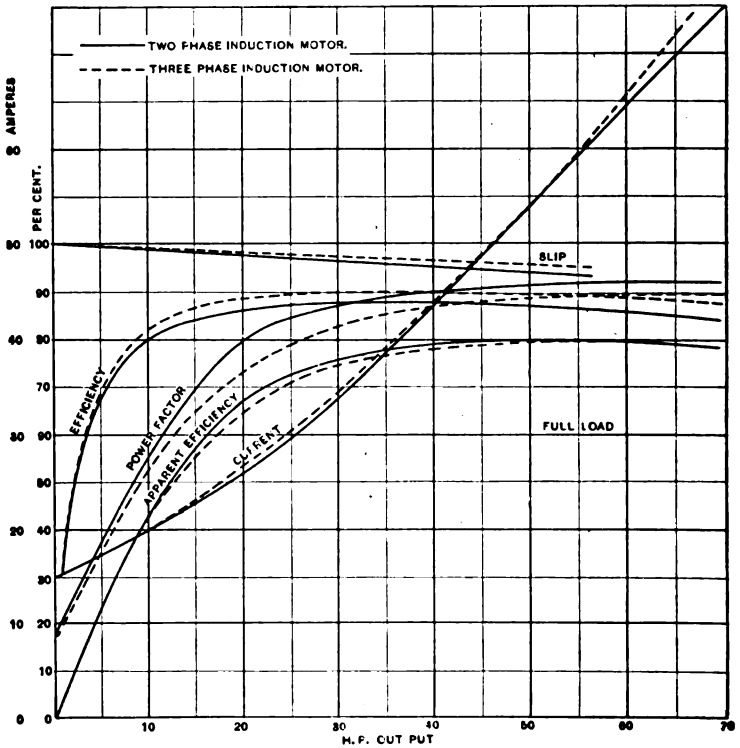

FIG. 5.—Comparative Characteristics of European and American Induction Motors.

We will now pass to the consideration of the composite set of curves shown in Fig. 6. We have here an assemblage of the efficiency curves of both direct and alternating-current machines. These curves show that the efficiencies of the 25-cycle American motors very closely approximate the efficiencies of the direct-current American motors. On the other hand the 60-cycle American motors fall somewhat below those of the other machines, a fact probably to be accounted for by the higher frequency at which they operate.

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The curves shown in the lower half of Fig. 6 are quite as interesting as those appearing above. Here the real currents flowing in direct current transmission lines are given. The three-phase curve, however, represents the values of the actual three-phase currents per line multiplied by $1\frac{1}{2}$, and the two-phase curve shows the actual two-phase line currents multiplied by two. The

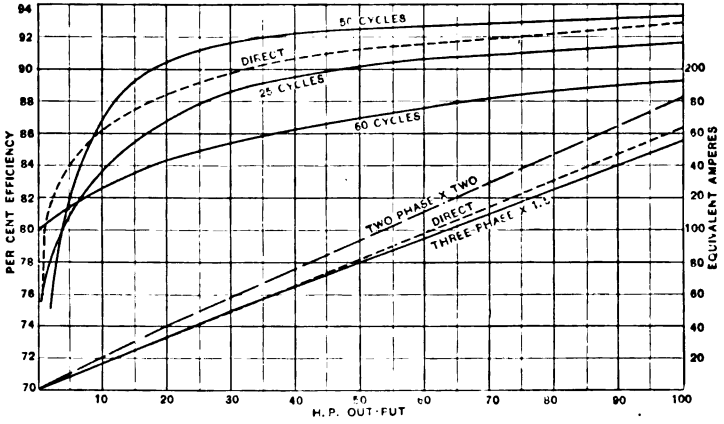

FIG. 6.—Relative Efficiency and Current Consumption of Direct Current and Induction Motors.

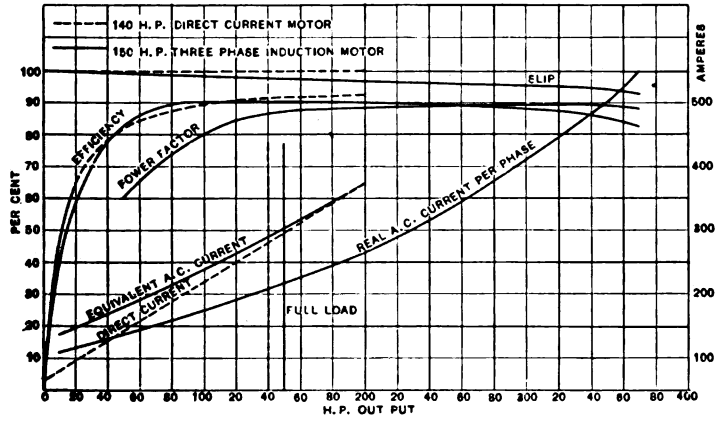

FIG. 7.—Comparative Characteristics of Direct Current Motor and Induction Motor.

current curves, give us, therefore, the equivalent values for the three systems. From this it appears that, in spite of the power factor which is to the disadvantage of the three-phase machines, the equivalent current performance of these machines is somewhat better than that of direct-current machines. Moreover, it is to be remembered that the two-phase currents here shown relate to two-phase, four wire distribution. Should the equivalent

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two-phase current curve be drawn representing the operation of two-phase motors by the two-phase three-wire system, the resulting equivalent current curve would also fall below that of the direct-current curve. In point then of current required, the induction motor operating at full load does not seem, in its performance, to fall below what is standard in connection with direct-current motors.

To enable us to get some idea of the relative performance of direct current and induction motors at various degrees of loading, the curves of Fig. 7 are given. They represent the performance of two motors made by the General Electric Company. One of these developing 140-horse power is a direct current

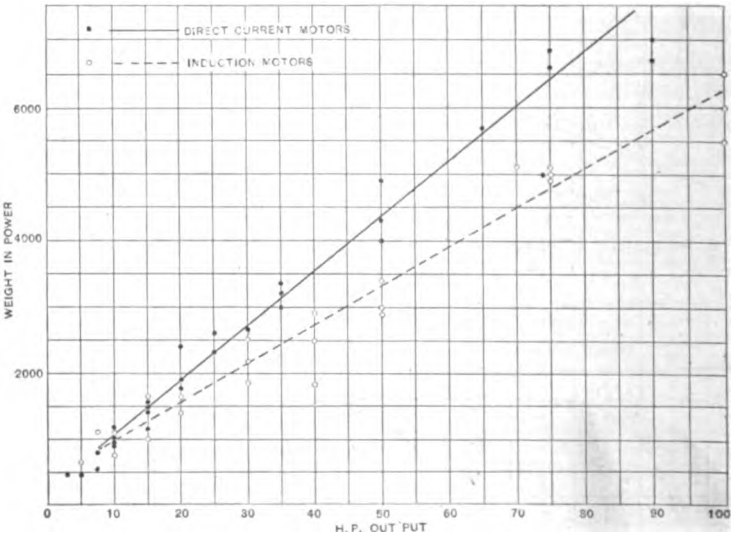

FIG. 8.—Comparative Weights of Direct Current and Induction Motors.

motor, its characteristics being shown by the dotted lines. The other is a 150-horse power three-phase induction motor. From these curves we see that, in point of slip, while the direct current motor maintains practically a constant speed from no load to full load, the induction motor suffers at full load a reduction in speed of 2½ per cent. At full load, we find that the equivalent alternating current taken by the three phase motor is practically the same as the direct current taken by the direct motor. At low loads, however, the equivalent current taken by the alternating current motor is over twice the value of that taken by the direct current motor, so that the performance, in point of current consumption of alternating current motors at light loads, is not so good as the performance of direct current motors.

On the other hand, if we consider the efficiency curves, we

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find that, while for both very light and heavy loads the efficiency of the direct current motor is better than that of the alternating current motor, the efficiency of an alternating current motor shows up to the best advantage for intermediate loads, above and below half load. Further than this, the curves illustrate very well the fact that it is possible to heavily overload an alternating current motor, and, at the same time, have it develop excellent efficiency and power factor characteristics. This is a point directly to the advantage of the alternating current machine, as, at excessively heavy loads, the direct current machine is apt to give trouble at the commutator.

Other elements to be considered in connection with motor performance are those bearing upon the construction of the machines. In Fig. 8 are exhibited a set of curves and plotted points which illustrate the relative weights of direct and alternating current motors. In small sizes of 10-horse power and under, it will be seen that the weights of direct and alternating machines are very nearly the same. For larger powers, however, above 30-horse power, the alternating current motor is, as a rule, considerably lighter than the direct current motor. In point of weight, then, the alternating current motor has a distinct advantage. As far as the general construction of the motors is concerned, the same degree of excellence in workmanship and insulation is obtainable in each class. In fact, the methods of manufacture may be said to be identical. The introduction of the commutator into the direct current machine is the point of greatest difference, and the commutator is, by many, regarded as the weakest point in direct current machines.

If we make a general review of what has been said concerning both types of motors, we find that, in point of construction, the machines are on very equal terms. In point of weight, the alternating current machine has the advantage. In point of full load efficiency and equivalent currents taken at full load, there is some advantage to be credited to the direct current machines. In point of efficiency at medium loads, the average performance of standard commercial machines shows that the alternating current motor has the advantage of direct current motors. At these loads, however, the equivalent line currents taken by the alternating current motors are considerably in excess of the currents taken by direct current motors. In point of starting torque, the direct current motor is undoubtedly superior to the alternating current motor for exceptionally heavy duty. Against this advantage of the direct current motor must be placed the elimination of the commutator in the alternating current motor, which, in some cases, at least, might make it worth while to install a 20-horse power induction motor in order to obtain the required starting torque, where otherwise a 10-horse power direct motor would suffice.

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It must further be remembered that, in this discussion, no consideration has been taken of the advantage which the alternating motor has over the direct current motor, which is given to it by the possibility of its being operated from high voltage mains. In making this comparison, the conditions have necessarily been limited to those existing in fields in which they may fairly be considered as competitors.

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OBITUARY.

JAMES HAMBLET.

James Hamblet was born at Boston, June 16, 1824, and died of pneumonia in Brooklyn, N. Y., January 2, 1900. He was elected an Associate Member of the INSTITUTE, November 1, 1887, and transferred to Membership, December 6, 1887.

Mr. Hamblet had become one of the most accomplished mechanicians of the day in 1853, when he took service with William Bond & Son, of Boston, for whom, during the following nine years, he constructed marine chronometers, regulators for noting sidereal time, and the many other accessories of an observatory, requiring in their construction the highest skill of the horologist's art. His name is found upon the observatory apparatus at Harvard and Columbia, and wherever the great telescopes of the fifty years past have been placed.

He was next associated in Boston for eight years with Benjamin Franklin Edmands, in the manufacture of electrical apparatus, under the firm name of Edmands & Hamblet—a business which, between 1862 and 1870, extended but little beyond telegraphic appliances. About 1868 this firm manufactured for the Laws Reporting Telegraph of New York City a few small gold indicators of a new design, intended for desk use, which, at that time, were considered of very superior workmanship. In this art there was not an equal opportunity for the exercise of the mechanician's skill; but it was a step gained for science that such a man had dropped a pursuit, in which he had become adept, to master another with his peculiar thoroughness.

It is seldom that two distinct arts have been brought closer together than were horology and telegraphy within his hands. Not only were they so united, but they were made close neighbors within the astronomical observatory, for it was through astronomy and the machinery of an observatory that he had found his way into the field of horology.

From telegraphy Mr Hamblet returned to horology. For the following six years (1870–1876) he was in charge of a half of E. Howard & Co.'s large works at Boston, and there his skill was

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once more applied to the building of astronomical regulators and the higher class of clocks. Again, in 1876, he returned to the manufacture of electrical instruments, having been appointed manager of the Electrical Construction Company of California, and for the following two years his home was in San Francisco. Few men have been better prepared for a particular work, and it was characteristic of Mr. Hamblet that he was always a most enthusiastic laborer in whatever field he was engaged. It is hardly probable that Mr. Hamblet served one apprenticeship after another merely to prepare himself for his later work; but the twenty-five years thus occupied by a man of his observation and inventive faculty must have wrought from horology, telegraphy and astronomy some new art, if, among them, a new art might be found. The Time System, which he established in 1878 for the Western Union Telegraph Company in New York, was a product that was natural, if not inevitable. The conception of such a work may not have been new. Its essential features had been suggested by several inventors. As early as 1841, such a system was patented by Alexander Bain. But to weave together the arts of which he was master into another in a manner that thousands of clocks throughout the country might be cheaply and effectually timed from a distant center was a work yet left for a man adept in horology, who was acquainted with the observatory and the telegraph.

At that period there were practically two standards of time maintained by private concerns, each having its special clientage. Hammond's time was the official standard of the Stock Exchange, while Benedict had a larger following in the railroad and steamboat fields. Other jewelry firms also undertook to provide standard time for their customers. It was in this very circle that Mr. Hamblet expected to build up a business, and it was quite natural that there should have been some reluctance on the part of his future subscribers to surrender the prestige which they had attained. His association with the Western Union Telegraph Company, and the co-operation of the National Observatory, together with the obvious advantage of a recognized universal standard, enabled him to bring about a complete revolution in the method of time distribution then existing. As the organizer of the present system with which he was identified up to the date of his death, Mr. Hamblet occupied a specia

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field, and was consequently a prominent figure in telegraphic work. His ability led to his election or appointment to various offices in electrical and scientific circles. He served three years as a Manager and two years as a Vice-President of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, was President for ten years of the electrical section of the Brooklyn Institute of Arts and Sciences, a highly esteemed member of the New York Electrical Society and Old Time Telegraphers' Association.

Mr. Hamblet looked upon his work with a pride that was more than justified by its success; and at the end, a world that was friendly to this modest gentleman rejoiced that he had been spared a score of years to view the results of his beneficent labors and to know that as his monument they might occupy a worthy place among the arts of the century.

R. W. P

COATES WALTON SWOOPE.

Coates Walton Swoope, who has been an Associate Member of the INSTITUTE since January, 1898, died on the morning of October 7, 1901, at the age of 31 years.

He was born in Tyrone, Pa., in 1870; but in early childhood came to Philadelphia with his parents. After graduating from the Manual Training Schools of the city, he entered the University of Pennsylvania. Before the end of his course there he entered the expert course of the Edison Company at Schenectady, N. Y., and completed this in due time. After a brief interval, in which he was engaged in expert work in Philadelphia, he was engaged to take charge of the Course in Applied Electricity at the Spring Garden Institute, which had been started the year previous, but conducted unsuccessfully.

At once, on assuming control of his work, for which his training and experience had peculiarly fitted him, a phenomenal success was attained. Mr. Swoope, with unflagging energy and amid many difficulties, created a course at once original in methods and remarkable in results. His lectures were always profusely illustrated by lantern slides, diagrams, models and experiments. For the laboratory work he conducted, it was necessary to build special instruments. The results of his efforts are shown in the products of the Palmer Electrical Instrument Company, of which firm he was a member, as well as in the equip-

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ment of his laboratories. For use in his class work he wrote a text-book: "Lessons in Practical Electricity," which has been adopted in other schools as well. The second edition of this book has just been issued. He saw it just before he died.

Only a few days after organizing his classes for the present winter, he was taken suddenly ill, and after five days' sickness, passed away.

His absorbing interest in his work gave him little time for social affairs. He lived for his course of study, and his memory will be cherished by the hundreds of students who understood his vital interest in them.

Mr. Swoope was a member of the Franklin Institute. He was a contributor to the columns of the *Electrical World and Engineer*, and compiled the general index of the *Electrical World* of 1882-1896. He also prepared the column of "Industrial Science Notes" for the Philadelphia *Ledger* for several years.

A. J. R.

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THE INSTITUTE CONVERSAZIONE.

On the evening of April 12, 1901, was held the first Conversazione of the American Institute of Electrical Engineers at Columbia University. The Engineering Building and Havemeyer Hall, which were utilized on this occasion, were courteously placed at the disposal of the Institute by the University authorities. The Committee on Papers and Meetings appointed by President Hering had charge of the arrangements, and to different members were assigned the various exhibits. Other details were undertaken by the Electrical Engineering Department of the University and directed by Dr. Francis B. Crocker and Messrs. F. Sever and Fitzhugh Townsend. The affair was a most pronounced success in every particular. Over 1,200 invitations had been issued and 900 people attended. Although the accompanying catalogue gives a complete list of the various exhibits it cannot do justice to the technical interest of the event or the brilliant spectacular effect which was a revelation to those who had no previous conception of the magnitude of the display.

COMMITTEE OF ARRANGEMENTS.

W. S. BARSTOW, *Chairman.*

EDWARD CALDWELL,	T. C. MARTIN,
W. J. HAMMER,	CALVIN W. RICE,
R. T. E. LOZIER,	GEORGE F. SEVER,

DR. FRANCIS B. CROCKER.

1. Mr. W. S. Andrews.—

1. *Revolving Spark Experiment*, showing oscillating discharge occurring rapidly during the same half wave and proving that a short circuit in a high potential curcuit containing inductances and capacity ruptures itself instantly.

2. *Luminous Aluminum Cell.*

2. Mr. E. V. Baillard.—

1. *Faradmeter.*—A portable and convenient instrument for measuring electrostatic capacity.

2. *Bridge for Measuring Low Resistances.*

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3. Prof. George F. Barker and Prof. Arthur W. Goodspeed.—

Radiographs illustrating special features of Roentgen ray phenomena.

4. Mr. Charles L. Clarke.—

Synchronism and Phase Indicator for indicating when two alternating current machines are in synchronism and the phase relations of their electromotive forces. It is also applicable for showing the lag of a current behind the electromotive force, either in the same or another circuit, provided they have equal frequencies, and also for showing the phase relations of currents of the same frequency.

The instrument, as exhibited, which is intended for use in lighting and power stations, consists of two synchronous alternating current motors, which respectively drive two stroboscopic disks, the stroboscopic image formed opposite a scale indicating when the generators respectively supplying current to the motors are in synchronism or nearly so, and, in the latter case, which of the generators is running at the greater polar speed. When the generators are in synchronism, the stroboscopic image is stationary, and its position relative to the scale indicates the degree to which the electromotive force of one generator leads or lags behind the electromotive force of the other.

5. Mr. A. F. Clift.—

Telpherage System for the transportation of freight in small bulk, express matter, mail, etc., by means of an electric motor traveling upon an overhead cable obtaining current by rolling contact with a lighter wire above.

6. Dr. Francis B. Crocker.—

Magnetic Liquids, with apparatus in operation for showing the magnetic properties of liquids and for measuring their permeability.

7. Mr. H. P. Davis.—

Two Switch-board Panels, showing principally a phase shifting transformer, a power factor indicator, a synchronizer, an alternation meter, and various new indicating and integrating instruments.

8. Prof. W. S. Franklin.—

Magnesia Arc Lamp.—An electrolytic lamp on the Nernst principle, operating on 1,000 volts.

9. Dr. William E. Geyer.—

Incandescent Lamp Experiments.—Experiments employing incandescent lamps on circuits containing self-induction and capacity.

10. Mr. Caryl D. Haskins.—

1. *Power Factor Indicator* showing relation between real and apparent energy in an alternating current circuit.

2. *Single Coil Astatic Instruments.*—Instruments which, instead of using four coils, employ only one.

11. Mr. Peter Cooper Hewitt.—

High Power Electric Light from Gases.

1. One large tube lamp 500 to 1,000 candle-power lighting the room, using ordinary 115-volt direct current.

2. Experiments illustrating the conduction of electricity by gases.

3. Apparatus showing the relation of voltage to length and diameter of tube.

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12. Mr. William J. Hammer.—

1. *European "Nernst" and other Electric Lamps.* It is expected that certain of these lamps will be shown in operation during the evening.

2. *Mr. Waldemar Poulsen's Telephonograph or Telegraphone*, exhibited by Messrs. Lemvig Fog and Emil S. Hagemann, of Copenhagen, Denmark, and Mr. William A. Rosenbaum, of New York.

The apparatus consists of a brass drum, 11 x 5 inches, upon which is wound piano wire. Resting upon the wire is a tiny electromagnet, which is connected to a carbon telephone transmitter, a couple of cells of battery, and preferably an induction coil in the usual manner. When the transmitter is spoken into, it acts as a tap on the battery, causing currents of varying strength, in proportion to the strength of the sound waves, to pass through the electromagnet. The current causes the magnet to transversely magnetize the steel wire as the drum revolves, and the magnetic lines of force are permanently recorded therein. After the steel spiral is filled—which operation takes about 39 seconds, and permits the recording of 100 to 120 words—the tiny magnet is placed in its original position and connected with a Bell receiving telephone; the cylinder is again revolved, and as the magnetized steel wire passes before the poles of the electromagnet, it forms a species of magneto-electric generator, giving out currents of electricity of a strength and direction corresponding to the magnetization of the steel wire, which correspondingly affect a Bell telephone held to the ear, and reproduce the sounds and words originally spoken, with absolute fidelity.

In addition is also shown the band form of telephonograph and a dictation machine for office use.

3. *Collection of Aeronautical Pictures*, comprising photographs of Prof. S. P. Langley's Aerodrome, Sir Hiram S. Maxim's Flying Machine, Santos-Dumont's Dirigible Air-Ship, and Count Zeppelin's Balloon; together with Baloon tests made during the Aeronautical Congress, at the Paris Exposition of 1900, and by the Aero Club of France. Most of these photographs were taken by the exhibitor.

13. Mr. A. S. Hubbard.—

The Gould Storage Battery.

1. *Positive and Negative Plates*, having small amount of active material, which have gone through a series of charges and discharges, at half-hour and twenty minutes rates.

2. *An Automobile Battery Cell* with a "spinning" giving 450 square inches of surface per pound of lead.

3. *A Positive and Negative Plate* of automobile type of cell.

4. *An Unformed Plate* with delicate "spinning," giving 144 square inches per cubic inch of lead.

The feature of the battery is the increase of superficial area of the plate obtained by spinning or grooving with rotary knives, which force the lead up between them, forming ribs and grooves of any desired dimensions. Each rib is made independent by tying the ends with the main cross-bars, and not depending on any centre conductor or support, thus giving a low internal resistance.

14. Mr. M. R. Hutchison.—

Akouphone and Akoulalion.—Microtelephonic instruments so constructed as to reproduce and intensify sounds and still preserve their quality.

15. Prof. S. P. Langley.—

Bolometer Drawings and Diagrams showing construction and princi-

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ples employed, Smithsonian Reports of Astrophysical
and large map of Solar Spectrum. Two large picture
(See special descriptive matter prepared by Prof. Langley.)

16. Prof. Frank A. Laws.—

Radiographs of Alternating Current Wave Forms and charges.—These radiographs were made by the use of Cath the Braun pattern.

17. Mr. Otto T. Louis.—

1. *Electric Furnace.*—The furnace consists of several about 2 inches in diameter and ½ inch thick, arou platinum wire of 22 B. & S. gauge. The wire is put o that as the resistance increases with the heat the circ from series to parallel. The cylinders have longitu motions, and are held in position by clamps.

2. *Ohmmeter.*—An instrument for making direct mea trical resistances, from 10,000 to 10,000,000 ohms.

3. *55 cm. Wimshurst Influence Machine.*—This is s Ryan's apparatus. (See paragraph 25, page 921.)

18. Mr. Herbert Lloyd.—

Chloride Accumulators.

Cells of a special form of Chloride Accumulator designed purposes, as used on the 34th Street Cross-town Line, New Y Exide cells for vehicle purposes. Specimen plates.

19. Mr. H. R. Palmer.—

Fac-Simile Picture Telegraph in operation. A system where tone pictures, sketches, handwriting, etc., can be transmitted ov distances, employing ordinary telegraph circuits. The original p enlarged for the purpose of transmission and when received is graphically reduced to its normal size, thus giving an exact repro of the original. The enlargement is for the purpose of obtaining a contact surface for the transmitting stylus.

20. Messrs. Frank Perret, J. A. Barrett and W. H. Me croft.—

Storage Battery made on a unit system, whereby cells of differe are built up of universal units of definite capacity. Purely Plante tion. No oxydizing agents are used and nothing but pure lead su acid and water are employed for the process of construction.

21. Dr. Michael I. Pupin.—

Original Apparatus used in developing the recent inventic improvement of long-distance land and ocean telephony, consist location of inductance coils in the line at distances which are de fractions of a current wave length.

22. Col. Samuel Reber, U. S. A.—

1. *Wireless Telegraphy* in operation, employing metho[illegible] an[illegible]provements as worked out for the use of the U. S. Government.

2. *U. S. A. Field Telephone and Telegraph Kit* used in the [illegible] and Philippine campaigns.

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23. Mr. L. T. Robinson.—

Wave Fo *Indicator.*—An instrument consisting of a small syn-
chron connection with suitable commutating devices used for
wave shapes of alternating current.

by Messrs.
and Mr. Wi P. Rice.—

Apparatus, employing a modified form of Wehnelt inter-

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Ryan and Prof. J. O. Phelon.—

Alternating Current Waves.—A method for securing
ous diagrams or cards of alternating current values,
ly recorded by means of a simple form of pantagraph
minous diagram and operates a lead pencil. (Wims-
ted by Mr. Otto T. Louis.)

ville.—

g Machine.—A portable and self-contained splicing
dent pump and flexible hose, used for making a solder-
and cables, forming a cold weld. This machine has an
essure of 20 tons per square inch in the weld.

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choonmaker.—

Magnetic Field.—A demonstration of the field is to be
the particles of iron will appear to be in aerial suspension
ple.

mer A. Sperry.—

of storage battery for automobile work, with diagrams of dis-
rves.

Nikola Tesla.—

Experiments with an Electric Oscillator.—Demonstrations will
by Mr. Tesla at 8.45 and 10 o'clock.

Elihu Thomson.—

mo Static Machine.—This machine contains a small direct cur-
or, the windings of which are tapped and connected to two rings
primary alternating current for the operation of a step-up trans-
which gives a secondary current of about 20,000 volts, being
however, of regulation through a wide range. The tops of the
current waves of high potential obtained from this secondary
r are used to charge a number of glass plate condensers in
The rotating frame synchronously driven with the motor makes
on to the condensers periodically and in synchronism with the
current. The connection by the rotating frame is alternately
d in series, condenser plates being charged to 15,000 volts and
arallel, giving 150,000 volts when connected in series. The
refore furnishes from low pressure direct current, high
harges of definite polarity at the discharged terminals.

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2. *A* *Rotary Electrical Apparatus* consisting of an iron sphere
heavily plated with copper and mounted so that it may revolve on
any axi any plane. Surrounding this sphere are three coils in planes
at right s to each other. By suitably energizing these coils with poly-
phase cur ent the sphere may be made to revolve on any axis or in any

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direction, or it may be said to illustrate a three dimension polyphase system. This apparatus illustrates the principles of the Gyroscope and Bohnenberger Sphere.

3. *An Illuminated Disk* mounted on a shaft free to rotate and having applied to it in special ways alternating current magnetic fields, the rotations of the disk involving interesting paradoxes.

31. Mr. Fitzhugh Townsend.—

Alternating Current Wave Tracer.—In this device the contact is made during one-half of the period in contradistinction to the instantaneous contact method ordinarily employed.

32. Engrossed Resolutions.

Prepared by the American Institute of Electrical Engineers for presentation to the Institution of Electrical Engineers, London, Eng.

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CONSTITUTION.

[*Adopted May 13, 1884. Amended December 8, 1885, September 27, 1892, May 15, 1894, March 16, 1896 and May 21, 1901.*]

ARTICLE I.

1. The name of this association shall be the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

2. Its objects shall be the advancement of the theory and practice of Electrical Engineering and of the Arts and Sciences connected with the production and utilization of electricity, and the maintenance of a high professional standing among its members. Among the means to this end shall be the holding of meetings for the reading and discussion of professional papers and the publication of such papers, discussions and communications as may seem expedient.

ARTICLE II.

MEMBERSHIP.

1. The corporate members of the INSTITUTE shall be designated as Members and Associates. Members and Associates shall be equally entitled to all of the rights and privileges of the INSTITUTE, except eligibility to the offices of President and Vice President, which shall be limited to Members; and Members only shall be entitled to a diploma. There shall also be Honorary Members, who shall be entitled to all the rights and privileges of the INSTITUTE, except the right to vote for officers and hold office.

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2. A Member shall have been an Associate, and at the time of his transfer to membership he shall be not less than twenty-seven years of age, and shall be:

a. A Professional Electrical Engineer; or

b. A Professor of Electrical Engineering; or

c. A person who has done important original work, of recognized value to electrical science.

3. To be eligible to membership as a professional Electrical Engineer, the applicant shall have been in the active practice of his profession for at least five years; he shall have had responsible charge of work for at least two years, and shall be qualified to design as well as direct electrical engineering works. Graduation from a School of Engineering of recognized standing shall be considered the equivalent of one year's active practice.

4. To be eligible to membership as Professor of Electrical Engineering, the applicant shall have been in responsible charge of a course of Electrical Engineering at a college or technical school of recognized standing, for a period of at least two years.

5. An Associate shall be a person who is interested in or connected with the study or application of electricity.

6. Honorary Members may be chosen from among those who have rendered acknowledged, eminent services to electrical engineering or its allied sciences.

ARTICLE III.

ADMISSION, TRANSFER AND EXPULSION OF MEMBERS.

1. Honorary Members shall be proposed in writing by at least ten Members, and may be elected only by the unanimous vote of the Board of Directors, a ballot in writing to be forwarded by Members absent from the Directors' meeting. The election of an Honorary Member shall be deemed invalid if an acceptance is not received within six months after the date of his election.

2. An application for admission to the INSTITUTE as Associate shall be made in a form prescribed by the Board of Directors, and shall refer to at least three members or associates.

3. An application for transfer from the grade of Associate to that of Member shall be made in a form prescribed by the Board of Directors, and shall embody a full record of the general technical education of the candidate, and of his professional career. It shall be signed by the applicant, and shall refer to at least five Members

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by whom he is personally known. Each of these references shall be requested by the Secretary to fill out a prescribed confidential form, to be addressed to the Board of Directors. No such application for transfer shall be considered until at least five favorable replies have been received. The Board of Directors, or the Board of Examiners, in the event of failure of replies, or receipt of unfavorable replies, may call upon the applicant to furnish additional names. Should an applicant for transfer certify that he is not personally known by five members, the Board of Examiners may accept references for the deficiency to professional engineers of standing.

4. The reference to Members to whom he is personally known may be waived in case of foreign applications; but the applicant shall in that case refer to at least two professional engineers of recognized standing.

5. The Secretary shall issue at stated intervals to each Member and Associate whose address is known, a list of new applications for admission to the INSTITUTE, with the request that the Members and Associates make written communication to the Board of Direc tors, in case of objection to any of the candidates named. The Board of Directors shall not act upon any name until at least twenty days after the date of issue of said list.

6. All elections to Associate Membership, and transfers to grade of Membership, shall be by vote of the Board of Directors; two negative votes shall exclude a candidate.

7. The Board of Directors may refuse to elect or transfer any applicant whose character, reputation or professional conduct would make him, in the opinion of the Board of Directors, an undesirable member.

8. A member of any grade in the INSTITUTE may resign his membership by a written communication to the Secretary, who shall present the same to the Board of Directors; whereupon, if all his dues or other indebtedness have been paid, his resignation shall be accepted.

9. Upon the written request of ten or more Members or Associates that, for cause stated therein, a Member or Associate of the INSTITUTE be expelled, the Board of Directors shall consider the matter, and if there appears to be sufficient reason, shall advise the accused of the charges against him. He shall then have the right to present a written defence, and to appear in person before a meeting of the Board of Directors, of which meeting he shall receive

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notice at least twenty days in advance. Not less than two months after such meeting, the Board of Directors shall finally consider the case, and if in the opinion of the Board of Directors a satisfactory defence has not been made, and the accused Member has not in the meantime tendered his resignation, he shall be expelled.

ARTICLE IV.

DUES.

1. The entrance fee, payable on admission to the INSTITUTE, shall be five (5) dollars. A fee of ten (10) dollars shall be paid on transfer to the grade of Member, which shall include the fee for a diploma.

2. The annual dues shall be fifteen (15) dollars for Members and ten (10) dollars for Associates.

3. The annual dues of Members and Associates residing in foreign countries other than Canada and Mexico, shall be ten (10) and five (5) dollars, respectively.

4. Honorary Members shall be exempt from all payments.

5. Persons elected after six months of the fiscal year have expired, shall pay one-half of the amount of dues for that fiscal year.

6. A Member or Associate in good standing, by the single payment of two hundred (200) dollars in addition to his entrance fee, shall become exempt from all future payments for dues or transfer fee. All money thus paid shall be invested as a permanent fund, of which the interest only shall be subject to appropriation for current expenses.

7. A Member or Associate who has been dropped as delinquent may be reinstated by the Board of Directors upon payment of all back dues, retaining his original date of election, and shall be entitled to a complete file of the published TRANSACTIONS corresponding with said payment, provided the same are in stock; or such Member or Associate shall have the option of reelection to the same grade, and payment only of his indebtedness up to the time he was dropped from the list.

ARTICLE V.

OFFICERS.

1. The officers of the INSTITUTE shall be a President, six Vice-Presidents, twelve Managers, a Secretary and a Treasurer, who shall hold office as follows:

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2. The President, the Secretary and the Treasurer for one year, the Vice-Presidents for two years, and the Managers for three years. The President, a Vice-President or a Manager shall not be eligible for immediate reelection to the same office. At each annual meeting, a President, three Vice-Presidents, four Managers, a Secretary and a Treasurer shall be elected in the manner prescribed below, whose terms of office shall commence upon the fourth Friday in September.

3. A vacancy in the office of President shall be filled by the senior Vice-President; a vacancy in the office of Vice-President shall be filled by the senior Manager. Seniority between officers of same rank and date of election shall be determined by the date of their election as Associates. All other vacancies shall be filled by the Board of Directors for the unexpired term. Such succession to office or appointment by the Board of Directors shall not render an officer ineligible for immediate election to the same office.

4. No officer shall receive, directly or indirectly, any salary, compensation or emolument from the INSTITUTE, either as such officer or in any other capacity, unless authorized by a vote of a majority of the entire Board of Directors.

5. No officer shall be interested, directly or indirectly, in any contract relating to the operations conducted by the INSTITUTE, nor in any contract for furnishing supplies thereto, unless expressly authorized by the by-laws and by the unanimous vote of the Board of Directors.

6. To provide for the officers already holding office when this Constitution shall go into effect, their terms shall be considered as dating from the time of the Annual Meeting as set forth in the Constitution which this Constitution supersedes, instead of from the fourth Friday in September, as this Constitution specifies; and nothing in this Constitution shall operate to exclude from office any officer elected under the previous Constitution.

ARTICLE VI.

ELECTION OF OFFICERS.

1. During the first week in February of each year, the Secretary shall mail or deliver to each Member and Associate of the INSTITUTE residing in the United States, its territories, Canada or Mexico, a list of all Members and Associates, together with a form showing the offices to be filled at the ensuing annual election in May, and

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containing the names of the incumbents and a copy of sections 1 and 2 of this article, with the request that nominations be made for the various offices to be filled. These nominations shall not be signed, and shall be enclosed in an envelope identified on the face by the name of the sender. To be considered, nominations must reach the Secretary prior to March first.

2. The Secretary shall submit to the Board of Directors a classified list of all nominations received, from which the Board of Directors shall prepare, during the month of March, a complete ticket, to be headed: "Directors' Nominees," containing the names of those whom the Board of Directors deem best suited for the offices falling vacant; provided that upon the request of two Directors at the meeting at which the "Directors' Nominees" ticket is prepared, the name of a second nominee for President shall be placed on the ticket, selected from the four names receiving the highest number of votes for President; and provided further, that the names for the office of Vice-President shall be selected with a view to maintaining a geographical distribution of the incumbents of this office. This ticket shall be printed on the same sheet with a second list, headed: "General Proposal List," containing all the eligible names proposed and the number of votes cast for each; provided that no name shall appear which shall not have received at least two per cent. of the entire number of votes cast.

3. The voting for officers shall be restricted to the names on the General Proposal List provided for in Section 2 of this Article. This sheet, together with an envelope on which shall be printed the title of the INSTITUTE, the name and address of the Secretary, and the words: "Official Voting Envelope—Enclosing a Ballot Only," shall not later than the 15th day of April, be mailed by the Secretary to every Member and Associate in good standing, together with a copy of Sections 3 and 4 of this Article; provided, that any qualified Member or Associate not having a ballot and envelopes shall be entitled to obtain them from the Secretary at any time before the ninth day of May.

4. All names voted for shall be written, printed or otherwise marked on a single ticket or ballot, which shall be enclosed in a sealed, unmarked and unidentified inner envelope of any suitable character, which shall in turn be enclosed either in the "Official Voting Envelope" (received from the Secretary), or any other envelope, marked on its face; "Non-Official Voting Envelope—Enclosing a Ballot Only." The outer envelope of either class shall be identified by the name of the sender on its face, shall be sealed,

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and in order to be counted, shall reach the Secretary not later than the ninth day of May. The Secretary shall preserve, unopened, all ballots received after the ninth day of May.

5. The President at the Directors' meeting to be held in April, shall appoint, subject to the approval of the Board of Directors, five Members or Associates, not members of the Board of Directors, to constitute the Committee of Tellers; should this Directors' meeting not be held, the President shall appoint this Committee by letter to the Secretary, who shall notify the members thereof.

6. Any Member or Associate who shall deliver to the Secretary on or before the ninth day of May, a written petition signed by at least twenty Members or Associates, stating their desire that he be a member of the Committee of Tellers, shall also be a member of that Committee; provided that the aforesaid signatures shall not have appeared on another similar petition.

7. The Committee of Tellers shall meet at the office of the INSTITUTE as soon after the ninth day of May as possible, and shall receive, unopened, all ballots from the Secretary, who shall also make to it a written report of the number of ballots received on and before and after the ninth day of May. It shall forthwith proceed, in secret, to count the vote, and shall prepare and sign a report of the results of the vote, which shall be sealed, and shall remain in the possession of the Chairman of the Committee, who shall hand this report to the presiding officer at the ensuing annual meeting. The presiding officer shall then cause this report to be read, and shall declare duly elected the eligible persons receiving the greatest number of votes for the respective offices.

ARTICLE VII.

MANAGEMENT.

1. The affairs of the INSTITUTE shall be managed by a Board of Directors under this Constitution and the general provisions of the laws under which it is incorporated. The Board of Directors shall consist of the officers of the INSTITUTE and the two junior Past-Presidents.

2. The Board of Directors shall have such powers and duties as are prescribed by statute for a Board of Directors.

3. The Board of Directors shall direct the investment and care of the funds of the INSTITUTE, shall make appropriations for

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specific purposes, shall pass upon all applications for admission or for transfer, shall act upon all questions of expulsion of members, shall appoint all employees and fix their salaries, and in general shall direct the business of the INSTITUTE, either itself or through the officers and committees.

4. The Board of Directors shall prepare and adopt a series of by-laws which shall govern its procedure and that of its committees, under this Constitution. Such by-laws shall be adopted or may be amended by a two-thirds vote of a quorum of the Board of Directors; provided, that the text of a proposed by-law or amendment shall be furnished to each member of the Board of Directors at least ten days before the meeting at which a vote of the same will be taken.

5. The President shall have general supervision of the affairs of the INSTITUTE, under the direction of the Board of Directors. He shall preside at the meetings of the INSTITUTE and of the Board of Directors at which he may be present, and shall be ex-officio member of all committees. He shall deliver an address at the Annual Convention. The Vice-Presidents, or in their absence, the Managers, in order of seniority, shall preside at meetings of the INSTITUTE and the Board of Directors in the absence of the President, and shall discharge his duties in case of a vacancy in the office. The President shall, at the meeting of the Board of Directors to be held on the fourth Friday in September, appoint the following Standing Committees: A Board of Examiners of five members; a Library Committee of five members; a Committee on Papers of five members; an Editing Committee of three members, a Committee on Finance of three members. He may also appoint temporary committees from time to time. The members of the Finance Committee shall all be members of the Board of Directors. All other standing committees shall include at least one member of the Board of Directors. All Members of the Board of Examiners shall be full members of the INSTITUTE.

6. The Secretary shall receive all moneys, and deposit them in the name of the INSTITUTE, reporting such deposit to the Treasurer, who shall receipt for the same. The Treasurer and the Secretary shall invest such funds as may be ordered by the Board of Directors. They shall also pay bills when audited by the Committee on Finance and approved by the Board of Directors. The Treasurer shall make an annual report and such other reports as may be prescribed.

7. The Secretary shall be, under the direction of the President and the Board of Directors, the Executive Officer of the INSTITUTE.

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He shall attend all meetings of the INSTITUTE and of the Board of Directors. He shall prepare the business for them, and record the proceedings thereof; he shall collect and deposit, subject to the order of the Treasurer, all moneys due the INSTITUTE. He shall personally certify the accuracy of bills or vouchers on which money is to be paid, and shall draw and countersign all checks, and these shall be signed by the Treasurer when such drafts are known to him to be proper and duly authorized by the Committee on Finance, and in accordance with warrants executed by the Secretary. He shall have charge of the books and accounts of the INSTITUTE, and shall furnish monthly to the Board of Directors a statement of receipts and expenditures and monthly balances. He shall present annually to the Board of Directors a balance sheet, and from time to time shall furnish such statements as may be required. He shall conduct the correspondence of the INSTITUTE, and keep full records. He shall be in responsible charge, under the President, the Board of Directors, and the Library Committee, of all the property of the INSTITUTE. He shall be responsible for the work of all employees of the INSTITUTE. He shall perform such other duties as may be assigned to him. His entire time must be devoted to the affairs of the INSTITUTE, unless otherwise authorized by the Board of Directors. He shall be paid a salary to be fixed by the vote of a majority of the entire Board of Directors.

8. The Board of Directors may, if deemed expedient, appoint assistants to the Secretary; one of these may hold the title of Assistant Secretary, who shall be under his immediate direction and shall aid him in all matters.

9. The Board of Directors may delegate any or all of its powers to an Executive Committee of seven members, consisting of the President, the Secretary, and the Treasurer, ex-officio, and four other members of the Board of Directors, which committee shall conduct the affairs of the Board of Directors between its meetings.

10. All committees shall be directly responsible to the Board of Directors, and shall act under its directions. The Board of Directors may, at any time, at its own discretion, remove any or all members of the committees and appoint others. The terms of the members of all standing and temporary committees shall terminate on the fourth Friday in September of each year, when the incoming President shall reconstitute the membership of all standing committees, and of such temporary committees as may have further duties to perform.

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11. The reports or actions of all Committees shall be addressed to the Secretary, and shall be by him referred to the Board of Directors.

12. *The Committee on Finance* shall have direct supervision of the financial affairs of the INSTITUTE. It may employ an expert accountant to assist in auditing the accounts. It shall approve all bills before payment, and shall make recommendations to the Board of Directors as to the investment of moneys, and upon all specific appropriations. No payments other than routine office expenses shall be made by the Secretary or Treasurer except upon the authorization of the Committee on Finance.

13. *The Library Committee* shall have general supervision of the Library and the rooms of the INSTITUTE, and the property therein. The Secretary shall be responsible to the Library Committee for his care of the property of the INSTITUTE. The Committee shall make recommendations with reference to books, and shall direct expenditures for books or other articles of permanent value, of such sums as may be appropriated for these purposes.

14. *The Committee on Papers* shall have general supervision of the papers to be presented to the INSTITUTE at its meetings, and of the discussions thereon. This Committee shall have the responsibility of collecting papers. It shall not accept papers from non-members without special authorization from the Board of Directors.

15. *The Editing Committee* shall edit all discussions of the papers presented. It shall be the duty of this Committee to limit as far as possible the amount of matter to be printed in the discussions. The printed discussions shall preferably be put in the third person. This Committee shall decide all questions regarding the publication of papers, discussions and communications.

16. *The Board of Examiners.* All applications for membership or for transfer that may be received by the Secretary shall be referred by him to the Board of Examiners, who shall pass upon the qualifications of the various applicants and shall report their recommendations to the Board of Directors, who shall pass upon the recommendations of the Board of Examiners.

17. The Board of Directors may, at its discretion, appoint Local Honorary Secretaries to represent the INSTITUTE in various parts of the world.

18. The following Members shall constitute a quorum of the Board of Directors:

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For all business prescribed by statute for a Board of Directors—Twelve Members.

For Expulsion of Members—Fifteen Members.

For all other business—Five Members.

19. The "vote of the Board of Directors" shall in all cases be the vote of a majority of the Members thereof present when the quorum required for the particular occasion is present.

ARTICLE VIII.

MEETINGS.

1. The Annual Meeting of the INSTITUTE shall be held on the third Tuesday of May, when a report of the proceedings of the INSTITUTE for the past fiscal year shall be furnished by the Board of Directors. This report shall be verified by the President, Treasurer and Secretary and a majority of the officers. It shall show: The whole amount of real and personal property owned, where located, where and how invested; the amount and nature of the property acquired during the last fiscal year and the manner of its acquisition; the amount applied, appropriated or expended during the year, and the purposes, objects or persons to or for which such applications, appropriations or expenditures have been made; the names and places of residence of persons who have been admitted to Membership in the INSTITUTE during such year; and all other facts bearing upon the status of the INSTITUTE. This report shall be filed with the records of the INSTITUTE and an abstract thereof entered in the minutes of the proceedings of the Annual Meeting. The reports of all officers shall be presented at the Annual Meeting, and the vote for officers for the ensuing year shall then be announced. Any other business may be brought before this meeting.

2. There shall also be held an Annual Convention of the INSTITUTE at some time after the Annual Meeting and before the first of December following, for the presentation and discussion of professional papers, and for the transaction of such other business as may be brought before it. The time and place of such Convention shall be fixed by the Board of Directors.

3. Other meetings of the INSTITUTE may be held at such time and places as the Board of Directors shall select, at which no business affecting the organization or policy of the INSTITUTE shall be transacted. Notice of all meetings shall be sent by mail, or otherwise, to all Members and Associates, at least ten days in advance.

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4. Every question affecting the organization or policy of the INSTITUTE which shall come before any meeting of the INSTITUTE shall be decided, unless otherwise provided by this Constitution, by the vote of a majority of a quorum.

ARTICLE IX.

STATE AND DISTRICT ORGANIZATIONS.

1. In each State or Territory of the United States in which there are fifty or more Members and Associates, the Board of Directors may authorize the formation of a State organization, for the purpose of more effectively carrying out the objects of the INSTITUTE.

2. The resident Members and Associates thus organized in any State shall have the privilege of being represented at the Annual Convention by one delegate to each fifty members. Such delegates shall be nominated by the resident Members and Associates of each State, by selecting names from the membership in the State, a list of which shall be forwarded by the Secretary, who shall also prepare and distribute the necesssary circulars for that purpose. The appointment of delegates shall be made by the Board of Directors in conformity with the expressed wish of the members. The Board of Directors shall also appoint alternate delegates, who shall serve in the absence of any delegate.

3. Official delegates thus appointed will be required to attend the Annual Convention, and shall be entitled to receive from the Treasury a sum of money sufficient to cover the cost of their railroad fare. They may cast as many votes as they shall hold proxies from their constituents upon any question brought before the Annual Convention.

4. The appointment as delegate shall not debar the incumbent from appointment or election to any other office in the INSTITUTE.

5. The Members and Associates of a State or Territory not entitled to a delegate may, upon request to the Board of Directors, be authorized to join with the Members and Associates of a contiguous State or States, and form a District, which, for the purpose of this Article, shall be considered as being one State, but shall be called a District, taking its name from the State within that District having the largest membership.

6. The Dominion of Canada and the Republic of Mexico shall

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each be considered as States, under the provisions of this Article.

7. Any State or Territory having a less number than fifty members may be represented by a delegate upon request to the Board of Directors, but such delegate shall not be entitled to receive from the Treasury of the INSTITUTE any portion of his expenses.

ARTICLE X.

GENERAL.

1. A quorum of the INSTITUTE shall consist of one-tenth in number of the total number of Members and Associates, residing in the United States and its territories, in Canada and in Mexico, as printed in the list provided for by Section 1, Article VI., issued each year, prior to the Annual Meeting.

2. Every Member or Associate entitled to vote at any meeting may so vote by proxy. Every proxy shall be executed in duplicate in writing by the Member or Associate himself, or by his duly authorized attorney, and one copy thereof filed with the Secretary before the date on which it is to be voted. No proxy shall be valid after the expiration of eleven (11) months from the date of its execution, unless the Member or Associate executing it shall have specified therein the length of time it is to continue in force, which shall be for some limited period. Every proxy shall be revocable at the pleasure of the person executing it.

3. For the purpose of electing officers, proxy voting shall be practiced only as provided in Article VI., and the Committee of Tellers therein named shall be considered a proxy Committee for the definite purpose stated.

4. The fiscal year of the INSTITUTE shall terminate with the thirtieth day of April.

ARTICLE XI.

AMENDMENTS.

1. Proposals to amend this Constitution shall be made in writing to the Board of Directors, and signed by at least twenty-five Members or Associates, and shall reach the Secretary not later than February first; the Board of Directors shall consider such proposals, and if in its opinion they are in accordance with

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the laws under which the INSTITUTE is organized, shall order the Secretary to send out a letter ballot upon such proposals. Votes, to be considered, shall be received not later than the ninth day of May. The Secretary shall refer these votes unopened to the Committee of Tellers, which shall count such votes and make a sealed report to the Board of Directors. This report shall be read at the Annual Meeting. An affirmative vote of a majority of the qualified Members and Associates shall be necessary to secure the adoption of an amendment.

2. Amendments so adopted shall take effect twenty days after their adoption; provided, that the officers of the INSTITUTE at the time any amendments become effective shall continue in office until the next fourth Friday in September.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

CATALOGUE OF MEMBERS.

JUNE 1ST, 1902.

HONORARY MEMBERS.

Name.	Address.	Date of Membership.
KELVIN, *Lord, D.C.L., LL.D., F.R.S.*	15 Eaton Place, London, S. W., England,	H.M. May 17, 1892
PREECE, *Sir.* WILLIAM. H., *K.C.B., F.R.S.*	Consulting Electrical Engineer, 13 Queen Anne's Gate, London, S. W., Eng.; residence, Gothic Lodge, Wimbledon.	H.M. Oct. 21, 1884

Honorary Members, 2.

MEMBERS.

ABBOTT, ARTHUR V., *C.E.* (*Vice-President.*)	Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City.	A Oct. 21, 1890 M Jan. 16, 1895
ACHESON, EDW. G.	President, The Carborundum Co., Niagara Falls, N. Y.	A Jan. 3, 1888 M May 1, 1888
ADAMS, ALTON D.	Consulting Engineer, Box 1377, Boston; residence, 39 Upland Road, Cambridge, Mass.	A April 18, 1893 M Jan. 17, 1894
AHEARN, THOMAS	Ahearn & Soper, Electrical Supplies, Ottawa, Ont.	A July 12, 1887 M Sept. 6, 1887
ALBANESE, G. SACCO	Ingenieur Conseil, No. 1 Rue Trachel, Nice, France.	A Sept. 20, 1893 M Sept. 27, 1899
ALBRIGHT, H. FLEETWOOD	Electrical Engineer, Western Electric Co., New York; residence, 60 Sayre St., Elizabeth, N. J.	A Sept. 27, 1892 M June 20, 1894
ALDRICH, WILLIAM S. [Life Member.]	Director, Thomas S. Clarkson Memorial School of Technology, Potsdam, N. Y.	A Mar. 15 1892 M April 25, 1900
ANDREWS, WM. S	Manager Central Station Sales, General Electric Co., residence, 242 Union St, Schenectady, N. Y.	A Mar. 5, 1889 M April 22, 1896
ANSON, FRANKLIN ROBERT	President, Salem Light, Heat and Power Co., Salem, Ore; residence, 355 Salmon St., Portland, Ore.	A Feb. 27, 1895 M Nov. 23, 1898

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Name.	Address.	Date of Membership.
ANTHONY, PROF. W. A.	(*Past President.*) Consulting Electrician, Cooper Union; residence, 313 W. 33d St., New York, N. Y.	A Dec. 9, 1884 M Jan. 6, 1885
ARMSTRONG, CHAS. G.	Consulting Electrical Engineer, Fisher Building, Chicago, Ill., and Maritime Building, New York City	A Sept. 27, 1892 M Aug. 31, 1898
ARNOLD, BION J.	Consulting Electrical Engineer, 1541 Marquette Bldg. and 4128 Prairie Ave., Chicago, Ill.	A Oct. 25, 1892 M Nov. 15, 1893
AYER, JAMES I.	General Manager American Electric Heating Corporation, Franklin and Sidney Sts., Cambridge, Mass.	A May 19, 1891 M April 19, 1892
AYRES, BROWN	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.	A Dec. 16, 1891 M Mar. 15, 1892
BADT, LIEUT. FRANCIS B.	Electrical Engineer, F. B. Badt & Co., 1504 Monadnock Block and 6506 Lafayette Ave., Chicago, Ill.	A April 19, 1893 M Mar 25, 1896
BAILLARD, E. V.	Manufacturer of Electrical Instruments and Fine Machinery, Fox Building, New York City.	A Dec. 3, 1889 M Jan. 16, 1895
BALDWIN, BERT L.	Mechanical Engineer, The Cincinnati Street R'way Co., 73 Perin Bldg., Cincinnati, O.	A April 22, 1896 M Nov. 18, 1896
BARBOUR, FRED FISKE	Manager, Sales Department, Pacific District, General Electric Co., Claus Spreckels Bldg., San Francisco, Cal.	A May 16, 1893 M Sep. 26, 1900
BARSTOW, WILLIAM S.	(*Manager*) Consulting, Electrical and Mechanical Engineer, 11 Broadway, (Telephone, 4671 Broad) New York City.	A Feb. 21, 1894 M April 26, 1899
BARTON, PHILIP PRICE	Assistant Superintendent, The Niagara Falls Power Co., Niagara Falls, N. Y.	A July 12, 1900 M June 28, 1901
BATCHELOR, CHAS.	Electrical Engineer, Exchange Court Bldg., 52 Broadway; residence, 33 W. 25th St., New York City.	A June 8, 1887 M July 12, 1887
BATES, JAMES H. *M. E.*	Engineering Department. The New York Edison Co., 57 Duane St., N.Y. City, Box 118 Hoboken, N.J.	A Sept. 6, 1887 M Oct. 1, 1889
BAYLIS, ROBERT NELSON	The Baylis Co., 140 Washington St., New York City.	A Oct. 1, 1889 M May 17, 1892
BEAMES, CLARE F.	Chief Engineer, Compania Mexicana de Gas y Luz Electrica. Ltd., Calle de Santa Clara No. 7. Apartado, Postal No. 267, City of Mexico.	A May 21, 1895 M Feb. 28, 1901
BECHTEL, ERNEST J.	Electrical Engineer and Superintendent of Lighting. The Toledo Railways and Light Company, Toledo, O.	A Mar. 24, 1897 M July 27, 1900
BEDELL, DR. FREDERICK,	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	A April 21, 1891 M May 19, 1896
BELL, PROF. A. GRAHAM	(*Past President.*) 1331 Conn. Ave., Washington, D. C., and Baddeck, N. S.	A April 15, 1884 M Oct. 21, 1884

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Name.	Address.	Date of Membership.
BELL, DR. LOUIS	Electrical Engineer, Boston; residence, 1056 Beacon St., Brookline, Mass.	A May 20, 1890 M June 18, 1890
BERNARD, EDGAR G.	Manufacturer, 450 Fulton St., Troy, N. Y.	A. Jan. 5, 1886 M July 12, 1887
BETTS, PHILANDER 3d	Electrical Engineer, Neeley Electric Co., 611 14th St., N. W.; residence, 213 Seaton St., N. E., Washington, D. C.	A Mar. 25, 1896 M Jan. 25, 1899
BILLBERG, C. O. C.	Electrical Engineer, 17 Hill Street, Newark, N. J.	A Mar. 21, 1894 M Feb. 27, 1895
BIRDSALL, E. T. *M. E.*	Consulting Electrical Engineer, New Rochelle, N. Y.	A June 8, 1887 M Nov. 1, 1887
BLADES, HARRY	Electrical Engineer, 419 Cass Ave., Detroit, Mich.	A April 19, 1892 M May 21, 1895
BLAKE, FRANCIS	Auburndale, Mass.	A Sept. 3, 1889 M Oct. 1, 1889
BLODGETT, GEO. W.	Electrical Engineer, B. & A. R. R. and Consulting Electrician, Boston, residence, Auburndale, Mass.	A July 12, 1887 M Sept. 6, 1887
BLOOD, JOHN BALCH	Blood and Hale, Consulting Engineers, 10 Post Office Square, Boston: residence, Newburyport, Mass.	A June 20, 1894 M Dec. 18, 1895
BOGGS, LEMUEL STEARNS	With Sargent & Lundy, 1000 East Van Buren St., Chicago, Ill.	A Sept. 20, 1893 M May 17, 1898
BOILEAU, WILLARD E.	General Superintendent Lighting and Power Dept. and Electrical Engineer, Columbus R. R. Co., Columbus, Ga.	A Sept. 19, 1894 M Mar. 25, 1896
BOSCH, ADAM	Sup't Fire Alarm Telegraph, Newark, N. J.	A April 15, 1884 M Jan. 6, 1885
BOTTOMLEY, HARRY	Bellows Falls Electric Light Co., Bellows Falls, Vt.	A April 2, 1889 M Jan. 22, 1896
BOURNE, FRANK	Electrical Engineer, 26 Cortlandt St., New York City.	A April 21, 1891 M Nov. 15, 1892
BOYER, ELMER E.	Foreman, Testing Department, Lynn Works, General Electric Co., Lynn, Mass.	A Sept. 25, 1895 M Mar. 25, 1896
BOYNTON, EDWARD C.	Mechanical Engineer, Chicago, Great Western Ry., 128 Third St., Newburgh, N. Y.	A Aug. 6, 1889 M Nov. 24, 1891
BRADLEY, CHAS. S.	(*Manager.*) President, Ampere Electro Chemical Co., 44 Broad Street, residence, 42 W. 84th St., New York City.	A May 24, 1887 M Dec. 6, 1887
BRADY, FRANK W., *M. E.*	Professor of Engineering New Mexico College of Agriculture and Mechanic Arts, Mesilla Park, N. M.	A June 20, 1894 M Mar. 28, 1900
BRENNER, WILLIAM H.	Constructing Engineer, Care of Frazar & Co., Yokohama, Japan.	A Sept. 20, 1893 M Mar. 21, 1894

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Name.	Address.	Date of Membership.
BRINCKERHOFF, HENRY MORTON	General Manager, Metropolitan West Side Elevated R. R.: 1001 Royal Insurance Bldg., Chicago, Ill.	A Sept. 23, 1896 M Dec. 16, 1896
BROOKS, MORGAN	Professor of Electrical Engineering, University of Illinois, Urbana, Ill.	A May 20, 1890 M June 17, 1890
BROWN, J. STANFORD, *E.E.*, [Life Member.]	Consulting Electrical Engineer, Cor. Sec'y, Carpenter Steel Co., 1 Broadway; Vice-Pres't and Treas. New York Realty and Trust Co; Treas., of the Realty-Loan Trust Co., 489 5th Ave.; New York City; residence, Reading, Pa.	A Sept. 6, 1887 M Nov. 1, 1887
BROWNE, SIDNEY HAND.	Consulting Engineer, Duncan and Browne, Md. Tel Bldg., P. & A Tel. Bldg., Pittsburg, Pa.: residence, The St Paul Apartments, Baltimore, Md.	A Apr 28, 1897 M Nov. 23, 1898
BRUSH, CHAS. F.	Electrical Engineer, 453 The Arcade, Cleveland, O.	A April 15, 1884 M Oct. 21, 1884
BUCK, HAROLD W.	Electrical Engineer, Niagara Falls Power Co., Niagara Falls, N. Y.	A Jan. 16, 1895 M Apr. 26, 1901
BURCH, EDWARD P.	Consulting Electrical Engineer, 1210 Guaranty Building, Minneapolis, Minn.	A Jan. 28, 1898 M May 17, 1898
BURGESS, CHAS. FRED'K.	Ass't Professor of Electrical Engineering, University of Wisconsin, residence, 245 Langdon St., Madison, Wis.	A Mar. 25, 1896 M Apr. 26, 1901
BURLEIGH, CHAS. B.	Electrical Engineer, General Electric Co., 200 Summer St., Boston, residence, 1 Oak Terrace, Malden, Mass.	A April 21, 1891 M Feb. 16, 1892
BURT, BYRON T.	Supt. Chattanooga Light & Power Co., Chattanooga, Tenn.	A Sept. 25, 1895 M Feb. 28, 1902
BURTON, WILLIAM C.	Electrical Engineer, J. G. White Co., 22a College Hill, London, E. C., Eng.	A Sept. 20, 1893 M Dec. 27, 1899
CAHOON, JAS. BLAKE	Consulting Engineer, 35 Nassau Street, New York City; residence, 31 Winyah Ave., New Rochelle, N. Y.	A June 17, 1890 M May 19, 1891
CALDWELL, FRANCIS CARY	Professor of Electrical Engineering, Ohio State University, residence, 401 W. 6th Ave., Columbus, O.	A June 20, 1894 M Jan. 24, 1902
CARICHOFF, E. R.	Electrical Engineer, Otis Elevator Co., 71 Broadway, New York City	A Mar. 21, 1894 M May 15, 1900

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Name.	Address.	Date of Membership.
CARHART, HENRY S.	Prof. of Physics, University of Michigan, Ann Arbor, Mich.	A Sept. 25, 1895 M April 22, 1896
CARUS-WILSON, PROF. CHARLES A.	Consulting Engineer, 41 Old Queen St., Westminster, London, Eng.	A April 18, 1894 M April 17, 1895
CHAMBERLAIN, J. C.	Vice President and Manager, The Electric Launch Co., Bayonne City, N. J.; residence, 1 West 81st St., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
CHANDLER, CHARLES F.	Professor of Chemistry, Columbia University, New York City.	A Jan. 20, 1891 M June 7, 1892
CHENEY, W. C.	Consulting Electrical Engineer, Chamber of Commerce Building, Portland, Or.; residence, Park Pl., Or.	A Sept. 22, 1891 M Nov. 21, 1894
CHESNEY, CUMMINGS C.	Chief Electrical Engineer, Stanley Electric M'f'g. Co., Pittsfield, Mass.	A June 20, 1894 M Nov. 22, 1899
CHILD, CHARLES TRIPLER	Technical Editor, *Electrical Review*, New York City; residence, 148 Claremont Ave., Montclair, N. J.	A Jan. 25, 1901 M June 28, 1901
CHILDS, ARTHUR EDWARDS, *B. Sc. M.E., E.E.*	Vice-President and Treasurer, The Light, Heat and Power Corporation, 23 Central St., Boston, Mass.	A June 20, 1894 M April 17, 1895
CHUBBUCK, H. EUGENE	General Manager, Quincy Lighting Companies, and Manager Quincy Railway and Carrying Co., Quincy, Ill.	A Dec. 4, 1888 M April 20, 1899
CHURCHILL, ARTHUR	Manager Purchasing Department, British Thomson-Houston Co., Rugby, Eng.	A April 15, 1890 M Jan. 17, 1893
CLARK, ERNEST P.	Electrical Engineer, B. Altman & Co., 19th St. and 6th Ave.; residence, 229 W. 18th St., New York City.	A Jan. 8, 1887 M Nov. 1, 1887
CLARKE, CHAS. L.	Electrical Engineer and Patent Expert, 31 Nassau St.; residence, 20 Beck St., Bronx Borough, New York City.	A April 15, 1884 M Jan. 6, 1885
COLBY, EDWARD A.	Consulting Engineer, Lock Box 113, Newark, N. J.	A April 2, 1889 M May 7, 1889
COMSTOCK, LOUIS K.	Electrical Engineer, George A. Fuller Co., 137 Broadway, New York City.	A Dec. 20, 1893 M Nov. 20, 1895
CONDICT, G. HERBERT	Consulting Engineer, Electric Vehicle Co., 49th St. & 8th Ave., New York City.	A July 12, 1887 M Sept. 6, 1887
CORNELL, CHARLES L.	Treasurer, Niles-Bement-Pond Co., 136 Liberty St., New York City.	A Feb. 7, 1890 M June 27, 1895
COSTER, MAURICE	Societe Industrielle d'Electricite, 45 Rue de la, Arcade, Paris, France.	A Sept. 25, 1895 M Mar. 25, 1896

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Name.	Address.	Date of Membership.
COWLES, ALFRED H.	President the Cowles Electric Smelting and Aluminum Co., 361 The Arcade; residence, 656 Prospect St., Cleveland, O.	A Mar. 5, 1886 M May 7, 1889
COX, FRANK POWELL	Electrical Engineer, General Electric Co, Lynn, Mass.	A Oct. 25, 1901 M April 25, 1902
CROCKER, FRANCIS BACON [Life Member.]	(*Past President*) Professor of Electrical Engineering, Columbia University; residence, 14 W. 45th Tel. 3823 38th New York City.	A May 24, 1887 M April 2, 1889
CROSS, CHARLES R.	Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
CUSHING, HARRY COOKE, JR.	Electrical Consulting and Constructing Engineer, 39 Cortlandt St., New York City.	A Sept. 19, 1894 M Nov. 18, 1896
CUTTRISS, CHAS.	Electrician, The Commercial Cable Co., 20 Broad St., New York.	A Nov. 1, 1887 M Dec. 6, 1887
DAFT, LEO	Consulting Electrical Engineer, 50 Hartfield Road, Wimbledon, London S. W. Eng.	A Dec. 9, 1884 M Jan. 6, 1885
DARLINGTON, FREDERIC W.	Consulting Electrical and Mechanical Engineer, 1120 Real Estate Trust Bldg, Philadelphia, Pa.	A Sept. 19, 1894 M Nov. 25, 1895
DAVIDSON, A.	Cable Engineer and Electrician, Central and South American Telegraph Co, Lima, Peru.	A May 18, 1897 M Oct. 27, 1897
DAVIS, ALBERT G.	Manager, Patent Dep't. General Electric Co, Schenectady, N.Y.	A Mar. 23, 1898 M Sept. 26, 1900
DAVIS, CHARLES H, *C. E.*,	Consulting Engineer, Broad-Exchange Bldg New York City, 204 Walnut Place, Philadelphia, Pa., 4 State Street, Boston, Mass.	A Mar. 18, 1890 M June 17, 1890
DAVIS, HARRY PHILLIPS	Engineer of Detail Dept., Westinghouse E. & M. Co.; residence, 327 Neville St., Pittsburg, Pa.	A Jan. 25, 1901 M Sept. 27, 1901
DAVIS, MINOR M.	Traffic Manager and Assistant Electrical Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 6, 1886 M May 16, 1893
DAWSON, PHILIP	Consulting Engineer, Lennox House, Norfolk St., Strand, London, W. C., Eng.	A Sept. 25, 1895 M Feb. 17, 1897
DECKER, EDWARD P.	Engineer, with Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City; residence, 496 Second St., Brooklyn, N. Y.	A Feb. 26, 1896 M Oct. 27, 1897
DELANY, PATRICK BERNARD	Inventor, South Orange N. J.	A April 19, 1884 M Nov. 24, 1891
DENHAM, JOHN	Electrician, Cape Government, Cape Town, South Africa.	A Jan. 24, 1900 M May 15, 1900

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Name.	Address.	Date of Membership.
DICKENSON, SAMUEL S.	Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N. S.	A Mar. 6, 1888 M Oct. 1, 1889
DIEHL, PHILIP	Inventor, Singer Sewing Machine Co., 508 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Dec. 9, 1884
DION, ADOLPHE ALFRED	General Supt., The Ottawa Electric Co., Sparks St., Ottawa, Ont.	A Jan. 7, 1890 M Nov. 15, 1893
DOANE, SAMUEL EVERETT [Life Member.]	Engineer National Electric Lamp Co., Marlborough, Mass.	A Aug. 6, 1889 M June 27, 1895
DODGE, OMENZO G., PROF.	U. S. Navy, Naval Academy, Annapolis, Md.	A Sept. 20 1893 M April 17, 1895
DOYER, H.	Consulting Electrical Engineer, 8 Phoenixstraat Delft, Holland.	A Jan. 7, 1890 M Mar. 18, 1890
DOMMERQUE, FRANZ J.	Chief Engineer, Kellogg Switchboard and Supply Co., cor. Congress and Green Sts., Chicago, Ill.	A Oct. 17, 1894 M Mar. 25, 1896
DONNER, WILLIAM H.	Ingleside, 31 Lyndhurst Road Hampstead, Eng.	A Nov. 18, 1890 M Dec. 16, 1890
DOW, ALEX	Manager, Edison Illuminating Co., 18 Washington Ave.; residence, 844 Cass Ave., Detroit, Mich.	A Sept. 20, 1893 M Dec. 18, 1895
DUDLEY, CHARLES B	Chemist, Penn. R. R. Co., Drawer 334, Altoona, Pa.	A Oct. 1, 1889 M Nov. 12, 1889
DUNBAR, F. W.	Engineer, Kellogg Switchboard and Supply Co., S. W. cor. Green and Congress Sts.; residence, 41 Madison Park, Chicago, Ill.	A Dec. 21, 1892 M May 16, 1893
DUNCAN, DR. LOUIS	(*Past-President*) Duncan & Browne, Consulting Engineers, Baltimore, Pittsburg, Philadelphia and 71 Broadway, New York City.	A July 12. 1887 M Sept. 6, 1887
DUNLAP, WILL KNOX	Supt. of Construction, Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	A Sept. 25, 1889 M June 24, 1895
DUNN, GANO SILLICK, *M.S., E.E.* (*Vice-President*).	Vice-President and Chief Engineer, Crocker-Wheeler Co., Ampere, N.J.; residence, 115 W. 71st St., New York City.	A April 21, 1891 M June 20, 1894
DYER, R. N.	Patent Attorney, 31 Nassau St., New York City.	A July 12, 1887 M Sept. 6, 1887
EDISON, THOMAS A.	Mechanician and Inventor, Llewellyn Park, N. J.	A April 15, 1884 M Oct. 21, 1884
EDGAR, C. L.	President Edison Elec. Illuminating Co. of Boston, 70 State St., Boston; residence, 259 Kent St., Brookline, Mass.	A Jan. 22, 1896 M May 19, 1896
EGGER, ERNST	Technical Director, Vereinigte Elektricitäts-Actien Gesellschaft, Simmeringstr, 187, Vienna, X., Austria.	A Feb 21, 1893 M Mar. 21, 1894
EMMET, W. L. R.	(*Vice-President.*) Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 6, 1893 M Jan. 17, 1894

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Name.	Address.	Date of Membership.
FESSENDEN, REGINALD A.	Special Agent, U. S. Weather Bureau, Washington, D. C.	A Oct. 21, 1890 M Dec. 16, 1890
FIELD, CORNELIUS J., *M. E.*	Sales Agent, Darracq Motor Cars, 133 West 38th St., New York City.	A June 8, 1887 M Nov. 1, 1887
FIELD, HENRY GEORGE	Consulting Engineer, Field & Hinchman, 1206 Majestic Building, Detroit, Mich.	A April 22, 1896 M Dec. 16, 1896
FIELD, STEPHEN D.	Electrical Engineer, Stockbridge, Mass.	A April 15, 1884 M Oct. 21, 1884
FISCHER, GUSTAVE J.	Engineer for Tramway Construction, Public Works Department, Sydney, N. S. W.	A Jan. 20, 1891 M May 17, 1898
FISH, WALTER CLARK	Manager Lynn Works, General Electric Co., Lynn, Mass.	A June 26, 1891 M Feb. 26, 1896
FISHER, HENRY W.	Electrician and Director of Elec. and Chem. Laboratories; The Standard Underground Cable Co., Pittsburg, Pa.	A Jan. 16, 1895 M April 26, 1901
FITZMAURICE, JAMES S.	(*Local Honorary Secretary*) Chief Engineer, The Electric Light Branch, 210 George St., Sydney, N. S. W.	A Sept. 20, 1893 M Mar. 21, 1894
FLACK, J. DAY, *M. E.*	Supt. Engineer of the International Smokeless Powder and Dynamite Co., Parlin, N. J.	A Dec. 6, 1887 M May 21, 1895
FORTENBAUGH, S. B.	Electrical Engineer, Metropolitan District Electric Traction Co., Ltd., 37 Hamilton House, Victoria Embankment, London E. C. Eng.	A April 17, 1895 M Dec. 16, 1896
FOSTER, HORATIO A.	Electrical Engineer, 650 Bullitt Building, Philadelphia, Pa.	A June 8, 1887 M Sept. 6, 1887
FOSTER, SAMUEL L.	Chief Electrician, Market Street Railway Co., Market & Valencia Sts.; residence, 3687 24th St., San Francisco, Cal.	A Feb. 26, 1896 M Nov. 18, 1896
FREEDMAN, WILLIAM H.	Professor of Electrical Engineering University of Vermont; residence, 222 So. Union St., Burlington, Vt.	A Mar. 18, 1890 M Dec. 18, 1895
FREEMAN, DR. FRANK L.	Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C.	A May 7, 1889 M Sept. 3, 1889
GALE, HORACE B.	Mechanical and Electrical Engineer, Natick, Mass.	A Nov. 15, 1892 M May 16, 1893
GARFIELD, ALEX. STANLEY	Engineer, 10 Rue de Londres; residence, 67 Avenue de Malakoff, Paris, France.	A Jan. 26, 1898 M June 28, 1901
GARRATT, ALLAN V.	Chief Engineer, Lombard Governor Co., 36 Whittier St., Boston; residence, 6 Newbern St., Jamaica Plain, Mass.	A April 2, 1889 M May 7, 1889

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Name.	Address.	Date of Membership.
GERRY M. H., JR.	Chief Engineer and General Manager, Missouri River Power Company, Helena, Mont.	A April 18, 1893 M Oct. 21, 1896
GEYER, DR. WM. E.	Stevens Institute of Technology, Hoboken, N. J.	A June 5, 1888 M Sept. 7, 1888
GHARKY, WILLIAM DAVID	Electrical Engineer, Firm of Clement & Gharky, 2347 Park Ave., Philadelphia, and 56 McGill Bldg. Washington, D. C.	A May 21, 1895 M Feb. 26, 1896
GIFFORD, CLARENCE E.	Professor of Engineering, Caton's College; residence, 878 Prospect Ave., Buffalo, N. Y.	A May 16, 1893 M Feb. 21, 1894
GLADSON, WM. N.	Professor of Electrical Engineering, University of Arkansas, Fayetteville, Ark.	A Dec. 28, 1898 M Jan. 24, 1902
GODDARD, CHRIS. M.	Secretary New England Insurance Exchange. Sec'y Underwriters' National Electric Ass'n, 55 Kilby St,, Boston, residence, 1008 Beacon St., Newton Centre, Mass.	A April 22, 1896 M Feb. 28, 1902
GOLDSBOROUGH, WINDER	ELWELL, *M. E.*, Professor of Electrical Engineering and Director of Electrical Laboratory, Purdue University, 113 South St., Lafayette, Ind.	A Mar. 21, 1893 M Jan. 25, 1899
GOLTZ, WILLIAM	Consulting Electrical Engineer, Goltz Engineering Co., 1504 Monadnock Block, Chicago, Ill.	A Oct. 27, 1897 M Feb. 23, 1898
GOODMAN, WM. GEO. TOOP	Electrical Engineer, Noyes Bros., Electrical Engineers, Box 361, Dunedin, New Zealand.	A Aug. 23, 1899 M May 15, 1900
GOSSLER, PHILIP GREEN	General Superintendent and Electrical Engineer, Royal Electric Co., 94 Queen St., Montreal, P.Q.	A June 20, 1894 M June 24, 1898
GOTSHALL, WM. C.	Consulting Engineer, 76 William St., New York City.	A Jan. 9, 1901 M Jan. 24, 1902
GREGG, TOM HOWARD	Supt. Electrical Construction, U. S. Light House Board, Tompkinsville, S. I., N. Y.; residence, 6 Wall St., St. George, S. I.	A Mar. 22, 1899 M Sept. 26, 1900
GUTMANN, LUDWIG	Consulting Electrical Engineer, 309 Y. M. C. A. Building, Peoria, Ill.	A Sept. 14, 1888 M Mar. 21, 1893
HADAWAY, W. S., Jr.	Electric Heating Engineer, 107 Liberty St., New York City.	A Nov. 21, 1894 M Oct. 21, 1896
HADLEY, ARTHUR L.	Electrical Engineer, Fort Wayne Electric Works, residence, 252 W. DeWald St., Fort Wayne, Ind.	A Oct. 17, 1894 M Mar. 22, 1901
HADLEY, FRED'K W. [Life Member.]	Electrical Eng'r, c/o Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York; residence, Arlington Heights, Mass.	A Aug. 5, 1896 M Feb. 28, 1901
HAFER, GEORGE, JR.,	Electrical Engineer, Cincinnati Gas and Electric Co., Cincinnati, O.	A Nov. 23, 1900 M Apr. 26, 1901
HALL, CLAYTON C.	Attorney-at-Law, and Consulting Actuary, Room 40, Maryland Life Building, 10 South St., Baltimore, Md.	A April 15, 1884 M Oct. 21, 1884

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Name.	Address.	Date of Membership.
HALL, JOHN L.	District Manager, Bullock Electric M'f'g. Co., 608–609 North American Bldg.; residence, 3116 Euclid Ave., Philadelphia, Pa.	A Sept. 22, 1891 M Dec. 20, 1893
HAMILTON, GEO. A.	(*Treasurer.*) Electrician, Western Electric Co., 463 West Street, New York; residence, 532 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Oct. 21, 1884
HAMMER, EDWIN W.	Electrical Engineer, 18 North 22d St., East Orange, N. J.	A Nov. 18, 1896 M June 23, 1897
HAMMER, WILLIAM J. [Life Member.]	Consulting and Supervising Electrical Engineer, 1406 Havemeyer Bldg, 26 Cortlandt St., [Tel 251 Cortlandt]; residence, 153 West 46th St., New York City.	A June 8, 1887 M July 12, 1887
HANCHETT, GEO. T.	Electrical and Technical Engineer, 123 Liberty St., N. Y.; residence, Hackensack, N. J.	A May 19, 1896 M Feb 15, 1899
HARRINGTON, WALTER E.	Electric Railway Engineer, 200 Market St.; residence, 554 Haddon Ave., Camden, N. J.	A Mar. 17, 1891 M May 19, 1899
HARTWELL, ARTHUR	Sales Manager, Westinghouse Electric and Mfg. Co.; residence, 505 S. Linden Ave., Pittsburg, Pa.	A May 15, 1894 M Nov. 20, 1895
HASKINS, CARYL DAVIS	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A Mar, 18, 1890 M June 20, 1894
HASSON, W. F. C.	Government Electrical Inspector, Territory of Hawaii, Honolulu, H. I.	A Mar. 18, 1890 M May 15, 1894
HAYES, HAMMOND V.	Electrical Engineer, the American Telephone and Telegraph Co., 125 Milk St., So. Boston; residence, Cambridge, Mass.	A Nov. 12, 1889 M Mar. 18, 1890
HAYES, HARRY E.	Asst. Electrician, American. Telegraph and Telephone Co., 22 Thames St., New York City.	A April 18, 1893 M Dec. 20, 1893
HEATH, HARRY E.	Chief Engineer, Eddy Electric M'f'g. Co., Windsor, Conn.	A Mar. 21, 1893 M Mar. 25, 1896
HEINRICH, RICHARD O.	General Manager, European Weston Electrical Instrument Co., 88 Ritterstrasse, Berlin, Germany.	A Oct. 1, 1889 M Oct. 25, 1892
HENSHAW, FREDERICK V.	Ass't. Engineer, Crocker-Wheeler Co., Ampere, N. J.; residence, 79 State St., Brooklyn, N. Y.	A Feb. 5, 1889 M Nov. 20, 1895
HERDMAN, FRANK E.	Mechanical and Electrical Engineer, Otis Elevator Co., Chicago; residence, Winnetka, Ill.	A Dec. 18, 1895 M Oct. 21, 1896
HERING, CARL [Life Member.]	(*Past President.*) Consulting Electrical Engineer, 929 Chestnut St.; Philadelphia, residence, Lehman Lane, Germantown, Philadelphia, Pa.	A Jan. 3, 1888 M June 5, 1888
HERRICK, CHARLES H.	Superintendent Isolated Lighting and Power Dep't., Edison Electric Illuminating Co., 3 Head Place, Boston; residence, 22 Herrick St., Winchester, Mass.	A April 21, 1891 M Jan. 17, 1893

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Name.	Address.	Date of Membership.
HERZOG, F. BENEDICT, *Ph. D.*	President, Herzog Teleseme Co., 51 W. 24th St., New York City.	A May 24, 1887 M July 12, 1887
HEWITT, CHARLES	Electrical Engineer, Union Traction Co., 809 Spruce Street, Philadelphia, Pa.	A Sept. 16, 1890 M May 17, 1892
HEWLETT, ERNEST HOLCOMBE	64 Victoria St., Westminster, London, England.	A Aug. 23, 1899 M. Dec. 27, 1899
HIBBARD, ANGUS S.	General Manager, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Nov. 24. 1891 M Feb. 16, 1892
HIGGINS, EDWARD E.	Treasurer McGraw-Marden Co., 32 Waverly Place, New York City; residence, Tarrytown, N. Y.	A June 8, 1887 M July 12, 1887
HILL, GEORGE, *C.E.*	Consulting Engineer, 100 Broadway, Rooms 7–8, 14th Floor (Telephone 6870, Cortlandt), New York City.	A April 19, 1892 M June 28, 1901
HOBART, HENRY M.	Engineer, Union Electricitäts Gesellschaft, 43 Dorotheen Strasse; residence, 123a Potsdame Strasse, Berlin, Germany.	A April 18, 1894 M Sept. 27, 1899
HOLMES, FRANKLIN S.	Electrical Engineer, 108 Fulton St., New York City; residence 318 E. 12th St., Brooklyn, N. Y.	A April 21, 1891 M June 20, 1894
HOSMER, SIDNEY	Electrical Engineer, Boston Electric Light Co, Ames Building, Boston, Mass.	A May 18, 1897 M Jan. 24, 1902
HOUSTON, EDWIN J., *Ph.D.* [Life Member.]	(*Past President.*) Prof. of Physics, Franklin Inst., residence, 1809 Spring Garden St., Phila., Pa.	A April 15, 1884 M Oct. 21, 1884
HOWELL, JOHN W.	Engineer, Lamp Works General Electric Co. Harrison; residence, Ballantine Parkway, Newark, N.J.	A July 12, 1887 M June 5, 1888
HOWELL, WILSON S.	Manager, Lamp Testing Bureau, 14 Jay St., New York City.	A Sept. 3, 1889 M Mar. 18, 1890
HOWLAND, LEWIS A.	Engineering Department, Canadian General Electric Co., Ltd., 6 Queen St., Montreal, Que.	A July 26, 1900 M Feb. 28, 1902
HUBLEY, GEORGE WILBUR	Superintendent and Electrical Engineer Louisville Electric Light Co.; residence, 1205 Garvin Place, Louisville, Ky.	A Sept. 19, 1894 M May 15, 1900
HUMPHREY, HENRY H.	Consulting Electrical Engineer, Suite 1305 Chemical Building, St. Louis, Mo.	A Dec. 16, 1896 M April 28, 1897
HUNTER, RUDOLPH M.	Expert and Counsellor in Patent Causes, 926 Walnut St., Philadelphia, Pa.	A July 13, 1886 M May 17, 1887
HUNTING, FRED S.	Chief Engineer, Engineering Department, Fort Wayne Electric Co., 325 West Washington St., Fort Wayne, Ind.	A Nov. 15, 1892 M May 16, 1893

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Name.	Address.	Date of Membership.
HUTCHINSON, DR. CARY TALCOTT [Life Member.]	Consulting Electrical Engineer, 56 Pine St., New York City.	A Feb. 7, 1890 M Dec. 16, 1890
HYDE, JEROME W.	Ass't Treasurer, The Springfield Steam Power Co., Wason Bldg. Springfield, Mass.	A June 8, 1887 M Nov. 1, 1887
INRIG, ALEC GAVAN	Globe Electrical Co., Arthur Villa, Agnes Road, Blundellsands, near Liverpool, Eng.	A Jan. 19, 1892 M May 17, 1892
IVES, EDWARD B.	Signal Officer, U. S. Volunteers, War Dept., Washington, D. C.	A April 2, 1889 M May 15, 1894
JACKSON, DUGALD C.	Consulting Engineer, Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.	A May 3, 1887 M June 17, 1890
JACKSON, FRANCIS E.	Incandescent Filaments Manufacturer, 128 Essex Ave., Orange; residence, 61 South Grove St., East Orange, N. J.	A Jan. 3, 1888 M June 17, 1890
JACKSON, HENRY	Telegraph Supt. and Engineer, The Lancashire & Yorkshire Railway Co., Horwich, Bolton-le-Moors, Lancashire, England.	A Mar. 21, 1894 M Dec. 19, 1894
JACKSON, JOHN PRICE	Professor of Electrical Engineering, Penn. State College, State College, Pa.	A Sept. 27, 1892 M Jan. 17, 1894
JACKSON, WM. B.	Engineer, with Stanley Electric M'f'g Co., Pittsfield, Mass.	A Aug. 13, 1897 M June 24, 1898
JANNUS, FRANKLAND	Attorney-at-Law, Solicitor of Patents, Room 1113; 141 Broadway, (Tel. 6273 Cortlandt), New York City.	A Nov. 12, 1889 M Mar. 18, 1890
JEHL, FRANCIS	I Meszaroo-uteza 14, I Stock Thur 12, Budapest, Hungary.	A June 27, 1895 M Jan. 22, 1896
JENKS, WILLIAM J.	Secretary, Board of Patent Control, 120 Broadway, New York City; residence, 497 4th St., Brooklyn, N. Y.	A June 8, 1887 M Nov. 1, 1887
JONES, FRANCIS WILEY [Life Member.]	Electrical Engineer, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 15, 1884 M Oct. 21, 1884
KEITH, DR. NATHANIEL S.	Mining and Metallurgical Engineer, Room 505, 95 Liberty St., New York City; residence, Arlington, N. J.	A April 15, 1884 M Jan. 17, 1894
KENAN, WM. R. JR.	c/o Traders' Paper Co., Lockport, N. Y.	A Jan. 20, 1897 M Apr. 26, 1901
KENNELLY, ARTHUR E. [Life Member.]	(*Past-President*) Consulting Electrical Engineer and Electrical Expert, 218 S. 4th Stt.; residence, The Lansdowne, N. 41st St. and Parkside Ave., Philadelphia, Pa.	A May 1, 1888 M May 16, 1899
DEKHOTINSKY, CAPT. ACHILLES.	Late Chief Electrician and Torpedo Officer, Imperial Russian Navy, 5526 Jefferson Avenue, Chicago, Ill.	A Oct. 27, 1891 M Nov. 22, 1899

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Name.	Address.	Date of Membership.
KILGOUR, MARTIN HAMILTON	Borough Electrical Engineer, 335 High St., Cheltenham, England.	A April 26, 1901 M Jan 24, 1902
KINSMAN, FRANK E.	Electrical Engineer, 95 Liberty St., New York City; residence, 836 Sherman Ave., Plainfield, N. J.	A Sept 27, 1892 M May 16, 1893
KIRKLAND, JOHN W.	c/o So. African General Electric Co., Hampson's Building, Durban, Natal, S. Africa.	A Mar. 21, 1894 M Sept. 26, 1900
KNOWLES, EDWARD R.	*E. E., C. E.* Consulting Electrical Engineer, 136 Liberty St., New York City; residence, 68 Downing Street, Brooklyn, N. Y.	A June 8, 1887 M July 12, 1887
KNOX, CHAS. EDWIN	With C. O. Mailloux, Consulting Electrical Engineer, 76 William St.; residence, 108 W. 122nd St., New York City.	A. May 16, 1899 M. Dec. 27, 1899
KNUDSON, A. A.	Electrical Engineer, Room 416, 32 Nassau St., New York City, Telephone 2100 John; residence, 758 Putnam Ave., Brooklyn, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
LANGE PHILIP A.	Superintendent Westinghouse Electric and Manufacturing Co., East Pittsburg, Pa.	A Mar 6, 1858 M June 5, 1888
LANGTON, JOHN [Life Member.]	Engineer, 72 Trinity Place, New York City.	A Mar. 6, 1888 M June 5, 1888
LARDNER, HENRY ACKLEY	J. G. White & Co., 29 Broadway, New York City.	A Dec. 19, 1894 M May 16, 1899
LA ROCHE, FRED. A.	Senior Member of F. A. La Roche & Co., 652-664 Hudson Street; residence, 28 W. 25th St., New York Ctty.	A Sept. 19, 1894 M Nov. 20, 1895
LAYMAN, W. A.	Assistant Manager and Treasurer, Wagner Electric M'f'g. Co., 2017 Locust St. St. Louis, Mo.	A Nov. 22, 1899 M Nov. 23, 1900
LEMP, HERMANN, JR.	Electrician, General Electric Co.; residence, 186 Allen Ave., Lynn, Mass.	A April 2, 1889 M Feb. 21, 1893
LEONARD, H. WARD [Life Member.]	Electrical Engineer, Pres't. Ward Leonard Electric Co., Bronxville, N. Y.; residence, Lawrence Park, N. Y.	A July 12, 1887 M Sept. 6, 1887
LESLIE, EDWARD ANDREW	General Manager, Edison Electric Illuminating Co., 360 Pearl St.; residence, 262 Hancock St., Brooklyn, N. Y.	A Jan. 16, 1895 M Feb. 17, 1897
LEVIS, MINFORD	Electrical Engineer, 36 North 4th St.; residence, 3413 Chestnut St., Philadelphia, Pa.	A Feb. 21, 1893 M June 23, 1897
LEYDEN, HARRY RUSSELL,	Hamilton Elec. Lt. & Cataract Pr. Co., Mgr., Hamilton, Ont.	A Nov. 23, 1900 M Feb. 28, 1901

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Name.	Address.	Date of Membership.
LIEB, JOHN WILLIAM, JR.	(*Vice-President*) Associate General Mgr., The N. Y. Edison Co., 53 Duane St.; residence, 869 West End Ave., New York City.	A Sept. 6, 1887 M Nov. 1 1887
LIGHTHIPE, JAMES A.	District Engineer, General Electric Co., Claus Spreckels Bldg., San Francisco, Cal.	
LINCOLN, PAUL M.	Electrical Supt. Niagara Falls Power Co., Niagara Falls, N. Y.	
LLOYD, HERBERT	Vice President and General Manager, Electrical Engineer and Chemist, The Electric Storage Battery Co., Allegheny Ave. and 19th St , Philadelphia, Pa.	lay 15, 1900 pr. 26, 1901 or. 27, 1898
LLOYD, JOHN E.	Chief Engineer and General Manager Cape Town Tramways, 49 Sir Lowry Road, Cape Town, S. Africa.	A M . 27, 1901 18, 18
LLOYD, ROBERT McA.	Electrician, 100 Broadway; residence, 5 Gramercy Park, New York City.	A Oct. , 1890 M Nov. , 1893
LOCKWOOD, THOMAS D., [Life Member.]	Electrical Engineer, and Advisory Electrician, American Telephone and Telegraph Co., 125 Milk St., P. O. Drawer 2, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
LOOMIS, OSBORN P.	Electrical Engineer, Newport News Shipbuilding and Dry Dock Co., Newport News, Va.	A Sept. 16, 1890 M Dec. 16, 1896
LORRAIN, JAMES GRIEVE, *M.I.E.E., M.I. Mech. E.*	Chartered Patent Agent, Norfolk House, Norfolk St., London, W. C., England.	A May 16, 1891 M May 15, 1894
LOVEJOY, J. R.	General Manager, Supply Dept., General Electric Co., Schenectady, N. Y.	A April 21, 1891 M Feb. 21, 1894
LOZIER, ROBERT T. E.	Manager, Bullock Electric Co., St. Paul Bldg., New York City; residence, 326 Richmond Terrace, New Brighton, S. I.	A May 20, 1890 M Jan. 24, 1900
LYMAN, JAMES [Life Member.]	Assistant Engineer, Chicago Office, General Electric Co , Monadnock B'ld'g., Chicago ; residence, 1308 Maple Ave., Evanston, Ill.	A Sept. 19, 1894 M Jan. 9, 1901
MACCOUN, ANDREW ELLICOTT	Supt. of the Electrical Dep't., The Carnegie Steel Co., Braddock, Pa.	A Nov. 20, 1895 M July 18, 1899
MACFARLANE, ALEXANDER, *D. Sc., LL.D.*	Lecturer on Mathematical Physics. Lehigh University, South Bethlehem Pa. residence, Gowrie Grove, Chatham, Ont.	A Jan. 19, 1892 M May 17, 1892
MAILLOUX, C. O. [Life Member.]	(*Manager*) Consulting Electrical Engineer, 76 William St., Telephone 2776 John ; residence, 48 W. 73d St., New York City.	A April 15, 1884 M Oct. 21, 1884

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Name.	Address.	Date of Membership.
MANSFIELD, ARTHUR N.	11th and Filbert Sts., Philadelphia, Pa.	A Dec. 20, 1893 M June 20, 1894
M.M.E.	Electrical Engineer, 687 Broadway; residence, No. 1 East 94th St., New York City.	A May 20, 1890 M Jan. 16, 1895
DENNIS, *Ph.B. C. E.*	President, City Heat and Light Co., Fostoria, O.	A Feb. 7, 1888 M May 1, 1888
	Asst. Engineer, Lamp Works, General Electric Co., N. J.	A Oct. 1, 1889 M Nov. 12, 1889
	Master Electrician, Navy Yard, Brooklyn; residence, 445 W. 21st St., New York City.	A Oct. 21, 1890 M Nov. 20, 1895
	c/o American Mutoscope and Biograph Co., 841 Broadway, New York City.	A April 19, 1892 M Jan. 17, 1893
IAM, JR.	Electrical Expert and Consulting Electrical Eng'r, 120 Liberty St., New York City; residence, 227 Arlington Ave. (Tel. 1282 Bergen) Jersey City, N. J.	A July 12, 1887 M April 21, 1891
MAYER, GEORGE M.	Mechanical and Electrical Engineer, 1681 Monadnock Bldg., Chicago, Ill.	A Dec. 16, 1890 M June 20, 1894
MAYNARD, GEO. C.	Electrical Engineer, Smithsonian Institution, Washington, D. C.	A April 15, 1884 M Dec. 9, 1888
MCCAY, H. KENT	Pres., McCay Engineering Co., 107 E. German St., Baltimore, Md.	A Sept. 16, 1890 M May 19, 1891
MCCROSKY, JAMES W.	Chief Engineer, La Capital Tramway Co. and Compañia de Luz y Fuerza Motriz de Cordoba, Reconquista 20, Buenos Aires, Argentina.	A Dec. 20, 1893 M Dec. 16, 1896
MCCROSSAN, J. A.	Manager and Electrician, Ferguson B. C. Canada.	A Oct. 18, 1893 M Dec. 18, 1895
MERSHON, RALPH D.	(*Manager.*) Consulting Engineer, Room, 840, 621 Broadway, New York City.	A Mar. 20, 1895 M Jan. 22, 1896
MILLIS, JOHN	Major of Engineers U. S. A., Seattle, Wash.	A July 7, 1884 M Mar. 3, 1885
MITCHELL, JAMES [Life Member.]	Constructing Engineer and Agent, General Electric Co., Caixa do Correio No. 954, Rio de Janeiro, Brazil.	A Sept. 25, 1895 M Mar. 25, 1896
MIX, EDGAR W.	Electrical Engineer, 12 Boulevard des Invalides, Paris, France.	A Sept. 3, 1889 M Mar. 20, 1895
MOLÉ, HARVEY EDWARD	Assistant Mechanical Engineer, Manhattan Railway Co., 74th St. and East River, New York City.	A Nov. 30, 1897 M Sept. 27, 1901
MOLERA, E. J.	Civil and Electrical Engineer, 606 Clay St., San Francisco, Cal.	A Jan. 16, 1892 M June 7, 1892

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Name.	Address.	Date of Membership.
MOORE, D. MCFARLAN	Inventor, Moore Electrical Co., 52 Lawrence St., Newark, N. J.	A Dec. 20, 1893 M June 20, 1894
MOORE, WM. E.	General Superintendent and Electrician, The Augusta Railway & Electric Co., Augusta, Ga.	A Jan. 22, 1896 M Sept. 27, 1899
MORROW, JOHN THOMAS	Supt. Electrolytic Plant, Boston and Montana Consolidated Copper and Silver Mining Co., Great Falls, Mont.	A Dec. 21, 1892 M April 18, 1894
DE MURALT, CARL L.	Electrical Engineer, Baden, Switzerland.	A May 15, 1900 M Nov. 22, 1901
MURPHY, JOHN	Superintendent Power Houses, The Ottawa Electric Co., Ottawa, Ont.	A [illegible]
MUSCHENHEIM, FRED'K A.	Electrical Engineer, Western Electric Co., 463 West St.; residence, 41 W. 31st St., New York City.	A [illegible] M [illegible]
NEILER, SAMUEL G.	Member of the Firm of Pierce, Richardson & Neiler, Consulting and Designing Engineers, 1405–12 Manhattan Building; residence, Hotel Del Prado, Chicago, Ill.	A Apr. [illegible] 1894 M Dec. 19, 1895
NICHOLS, DR. EDWARD L.	Professor of Physics, Cornell University; residence, 5 South Ave., Ithaca, N. Y.	A Oct. 4, 1887 M Dec. 6, 1887
NICHOLSON, WALTER W.	General Supt. Central N. Y. Telephone and Telegraph Co., Telephone Building, Utica, N. Y.	A May 15, 1894 M May 18, 1897
NOLL, AUGUSTUS	Contracting Electrical Engineer, 8 East 17th St., Telephone, 62, 18th; New York City.	A Sept. 27, 1892 M April 18, 1893
NUNN, PAUL N.	Chief Engineer, Telluride Power Co., Telluride, Colo.	A April 17, 1895 M Feb. 26, 1895
O'DEA, MICHAEL TORPEY	[Address unknown.]	A June 8, 1887 M Mar 25, 1896
OUDIN, MAURICE A.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 20, 1894 M Nov. 20, 1895
OWENS, ROBERT BOWIE	(*Local Honorary Secretary*) McDonald Professor of Electrical Engineering, McGill University, Montreal, P. Q.	A June 17, 1890 M Dec. 15, 1897
PAINE, F. B. H.	Westinghouse Electric and Mfg. Co., 120 Broadway; residence, 201 W. 78th St., New York City.	A Dec. 16, 1890 M Nov. 25, 1891
PAINE, SIDNEY B.	General Electric Co., 200 Summer St., Boston, Mass.; residence, 78 Cypress St., Newton Centre, Mass.	A June 8, 1887 M Nov. 1, 1887
PARKER, LEE HAMILTON	The Buenos Aires and Belgrano Electric Tramways Co., Calle Santa Fé No. 2457, Buenos Aires.	A Aug. 5, 1895 M Dec. 16, 1896
PARKS, C. WELLMAN	Civil Engineer, U. S. N., U. S. Naval Station, San Juan, P. R.	A July 12, 1887 M May 1, 1888
PARSHALL, HORACE FIELD	(*Local Honorary Secretary*), Consulting Engineer, Salisbury House, London Wall, E. C., London, Eng.	A Sept. 7, 1888 M Mar. 18, 1890

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Name.	Address.	Date of Membership.
PATTISON, FRANK A	Firm of Pattison Bros, Consulting and Constructing Electrical Engineers, 141 Broadway, New York City.	A Sept. 22, 1891 M Dec. 16, 1891
PEARSON, F. S.	Engineer, Room 811, 621 Broadway, New York City.	A Oct. 25, 1892 M Feb. 21, 1893
PECK, JOHN SEDGWICK	Electrical Designer, The Westinghouse E. & M Co., Pittsburg, Pa.	A Apr. 26, 1892 M May 15, 1900
PEDERSEN, FREDERICK	MALLING, *M. S., E. E.* Tutor in Mathematics, College of the City of New York, 17 Lexington Ave.; residence, 39 Washington Square, West, New York City.	A Sept. 20, 1893 M June 24, 1898
PEROT, L. KNOWLES	President of The Schuylkill Valley Illuminating Co., Phœnixville, Pa.	A Mar. 15, 1892 M Dec. 18, 1895
PERRINE, FREDERIC A. C., *D. Sc.*	President Stanley Electric M'f'g Co., Pittsfield, Mass.	A Sept. 16, 1890 M Dec. 16, 1890
PERRY, JOHN	Royal College of Science, South Kensington 34 Palace Gardens Terrace, London, W. England.	A Mar. 22, 1901 M June 28, 1901
PICKERNELL, F. A.	Chief Engineer, Amer. Tel. & Tel. Co., 125 Milk St., Boston, Mass.	A Feb. 7, 1890 M Mar. 18, 1890
PIERCE, RICHARD H. (*Local Honorary Secretary.*)	Pierce, Richardson & Neiler, Electrical Engineers, 1409 and 1410 Manhattan Bldg., Chicago; residence, 5434 Monroe Ave., Hyde Park, Ill.	A April 18, 1893 M Dec. 20, 1893
PIKE, CLAYTON W., *B.S.*	Electrical Engineer, Keller, Pike & Co., 112 N. 12th St., Philadelphia, Pa.	A Dec. 16, 1891 M Oct. 25, 1892
PINKERTON, ANDREW	Electrical Engineer, American Sheet Steel Co., Vandergrift Pa.	A Sept. 25, 1895 M June 28, 1901
PORTER, JOSEPH F.	*C. E.* President and Managing Engineer, Alton Railway, Gas and Electric Co., Alton, Ill.	A Sept. 6, 1887 M Nov. 1, 1887
POTTER, WM. BANCROFT,	Engineer Railway Dept., General Electric Co., Schenectady, N. Y.	A Jan. 22, 1896 M Mar. 25, 1896
PRATT, ROBERT J.	Electrician, Honolulu Iron Works, Honolulu, H. I.	A July 12, 1887 M Sept. 6, 1887
PUFFER, WM. L.	Assistant Professor of Electrical Engineering, Mass. Institute of Technology, Boston; residence, West Newton, Mass.	A Dec. 20, 1893 M April 17, 1895
RAE, FRANK B.	Electrical and Mechanical Engineer, Exchange Court, 52 Broadway, New York City.	A April 15, 1884 M Oct. 25, 1892
REBER, SAMUEL	Lieut. Col. U. S. A., Army Headquarters, Washington, D. C.	A Sept. 20, 1893 M Jan. 22, 1896
RECKENZAUN, FREDERICK,	Electrical Engineer, (Washington Bldg., Room 281,) 1 Broadway, New York City.	A Mar. 6, 1888 M June 5, 1888

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Name.	Address.	Date of Membership.
REDMAN, GEO. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec. Co., 82 Andrews St.; residence, 30 Park Ave., Rochester, N. Y.	A Feb. 27, 1895 M May 17, 1898
REID, THORBURN	Consulting Electrical Engineer, 136 Liberty St., New York City.	A Oct. 21, 1890 M June 24, 1898
REIST, HENRY G.	Designing Engineer, General Electric Co., 5 South Church St., Schenectady, N. Y.	A June 17, 1890 M Dec, 19, 1894
RENO, C. STOWE	Electrical Engineer, Triumph Electric Co., 610 Baymiller Street, Cincinnati, Ohio.	A Nov. 23, 1898 M July 18, 1899
RICE, CALVIN WINSOR	(*Manager.*) Second Vice-President, Nernst Lamp Company, Pittsburgh, Pa.	A Jan. 20, 1897 M April 28, 1897
RICE, E. WILBUR, JR.	Technical Director, The General Electric Co., Schenectady, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
RICHARDSON, ROBERT E.	Vice-President of Pierce, Richardson & Neiler, 1409 Manhattan Building residence, The Montague, Kansas City. General Manager, Kansas City, (Mo.) Electric Light Co.	A Sept. 19, 1894 M May 18, 1897
RIDLEY, A. E. BROOKE	Electrical Engineer and Contractor, Parrot B'ldg. San Francisco, Cal.	A Nov. 21, 1894 M Nov. 23, 1898
RIES, ELIAS E.	Electrical Engineer and Inventor, 116 Nassau St.; residence, 4 W. 115th St., New York City.	A July 12, 1887 M Sept. 6, 1887
RIKER, ANDREW L. [Life Member.]	Electrical Engineer, Short Hills, N. J.	A Nov. 1, 1887 M Dec. 18, 1895
ROBB, RUSSELL	With Stone & Webster, 93 Federal Street, Boston, Mass.	A Oct. 18, 1893 M May 21, 1895
ROBB, WM. LISPENARD	Professor of Physics, Trinity College, and 118 Vernon St., Hartford, Conn.	A Dec. 16. 1891 M Mar. 15, 1892
ROBERTS, E. P.	E. P. Roberts & Co., Consulting Engineers, Electric Building, Telephone 2656; residence, 95 Cornell St., Cleveland, O.	A Jan. 6, 1885 M Feb. 3, 1885
RODGERS, HOWARD S.	Electrical Engineer, care General Electric Co., 420 W. 4th Street, Cincinnati, O.; residence, 190 E. 2d St., Covington, Ky.	A Sept. 27, 1892 M May 16, 1893
ROHRER, ALBERT L.	Electrical Supt. Schenectady Works General Electric Co.; residence, 20 Union St., Schenectady, N. Y.	A Nov. 1, 1887 M May 1, 1888
ROLLER, FRANK W. *M.E.*	Electrical Engineer, Machado & Roller, Electrical Machinery, 203 Broadway, N. Y.; residence, Roselle, N. J.	A May 21, 1895 M Sept. 27, 1901
ROLLER, JOHN E.	Lieut. Commander U. S. N., Navy Department, Washington, D. C.	A Sept. 19. 1894 M May 19, 1896

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Name.	Address.	Date of Membership.
ROSA, EDWARD B.	Physicist, National Bureau of Standards, Washington, D. C.	A Feb. 17, 1897 M May 18, 1897
ROSS, NORMAN N.	Engineer, Boston Office Stanley Electric Mfg. Co., 203 Equitable Building, Boston, Mass.; residence, Somerville, Mass.	A Sept. 20, 1893 M Nov. 21, 1894
ROSS, ROBERT A.	Mechanical and Electrical Consulting Engineer, 17 St. John St., Montreal, P. Q.	A Sept. 27, 1892 M April 18, 1893
ROUQUETTE, WILLIAM F. B. [Life Member.]	Proprietor, Rouquette & Co., 47 Dey St., New York City.	A Mar. 21, 1894 M Dec. 19, 1894
RUSHMORE, DAVID B.	Ass't Electrician Stanley Elec. and M'f'g Co., residence, 202 South St., Pittsfield, Mass.	A Sept. 25, 1895 M Jan. 24, 1902
RYAN, HARRIS, J.	Professor of Electrical Engineering, Cornell University; residence, Cascadilla Place, Ithaca, N. Y.	A Oct. 4, 1887 M April 17, 1895
SACHS, JOSEPH	Electrical Engineer, The Johns-Pratt Company; residence, 4 Cone St., Hartford Conn.	A Mar. 15, 1892 M Dec. 15, 1897
SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*, [Life Member]	Engineer and Barrister, Broomhill, Tunbridge Wells, Kent, and 49 Grosvenor St., London, W. England.	A Feb. 7, 1888 M May 1, 1888
SAMPSON, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.	A Aug. 5, 1896 M Oct. 27, 1897
SANDS, H. S.	Consulting and Constructing Electrical Engineer, 1153 Market St., Wheeling, W. Va.	A Feb. 21, 1893 M Nov. 21. 1894
SARGENT, WILLIAM D.	Vice Prest. and General Manager, N. Y. & N. J. Tel. Co., 81 Willoughby St.; residence, 820 Union St., Brooklyn, N. Y.	A April 15, 1884 M Feb. 21, 1894
SCHEFFLER, FRED. A.	Contractor, Steam & Electric Plants James Beggs & Co., 9 Dey St., N. Y. City; residence, 33 Snowden Pl., Glen Ridge, N. J.	A May 16, 1893 M Jan. 26, 1896
SCHMID, ALBERT	Directen Genèral de la Société Industrielle d'Electricitè procèdès Westinghouse, 45 rue de l'Arcade Paris, France.	A Oct. 21, 1890 M April 17, 1895
SCHOEN, A. M.	Electrician, South Eastern Tariff Association, 433 Equitable Building, Atlanta, Ga.	A Sept. 20, 1893 M Dec. 16, 1896
SCHWEDTMANN, FERDINAND	General Sup't Wagner Electric M'f'g Co., 2017 Locust St., St. Louis, Mo.	A Nov. 22, 1899 M Nov. 23, 1900
SCOTT, CHARLES F.	(*Manager.*) Chief Electrician, Westinghouse Electric and Mfg. Co.; residence, 6214 Sellers St., East End, Pittsburg, Pa.	A April 19, 1892 M Jan. 17, 1893
SCOTT, JAMES B.	Consulting Engineer, 808 Maryland Trust Bldg.; residence, 847 Ducatel St., Baltimore, Md.	A Aug. 5, 1896 M May 17, 1898

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Name.	Address.	Date of Membership.
SETHMAN, GEORGE HENRY,	Mechanical and Electrical Engineer, Skinner & Sethman, 2305 Boulevard F., Denver, Colo.	A Nov. 23, 1900 M June 28, 1901
SEVER, GEORGE FRANCIS	(*Vice-Pres.*) Adj. Prof. of Electrical Engineering, Columbia University, New York City.	A Jan. 17, 1894 M May 19, 1896
SHAW, EDWIN C.	Mechanical Engineer, The B. F. Goodrich Co., Akron, O.	A May 17, 1892 M Feb. 27, 1895
SHEA, DANIEL W.	Professor of Physics, Catholic University of America, Washington, D. C.	A Dec. 20, 1893 M June 20, 1894
SHELDON, SAMUEL, *A. M., Ph.D.* [Life Member.]	(*Vice-Pres.*) Professor of Physics and Electrical Engineering. Polytechnic Institute; residence, 198½ Schermerhorn St., Brooklyn, N. Y.	A Dec. 16, 1890 M Oct. 27, 1891
SHEPARDSON, GEORGE D.	Professor of Electrical Engineering, University of Minnesota, Minneapolis, Minn.	A April 21, 1891 M Jan. 22, 1896
SINCLAIR, H. A.	Electrical Engineer, The Tucker Electric Co., 35 South William St., New York; 950 Bedford Ave. Brooklyn, N. Y.	A June 17, 1890 M Feb. 26, 1896
SMITH, FRANK E.	Consulting and Supervising Electrical Engineer, 183 Jessie St.; residence, 418 Eugenia Ave., San Francisco, Cal.	A Sept 19, 1894 M July 18, 1899
SMITH, FRANK STUART	Sawyer-Man Electric Co., 510 W. 23d St., New York City.	A Sept. 27, 1892 M April 18, 1893
SMITH, HAROLD BABBITT	Professor of Electrical Engineering, Worcester Polytechnic Institute; residence, 20 Trowbridge Road, Worcester, Mass.	A Nov. 24, 1891 M April 25, 1900
SMITH, JESSE M.	Expert in Patent Causes, Consulting Electrical and Mechanical Engineer, 36 Moffat Block, Detroit, Mich., and 218 Broadway, New York City.	A April 15, 1884 M June 26, 1891
SMITH, T. CARPENTER	Member of Firm of M. R. Muckle, Jr., & Co., 512 Stephen Girard Bldg; residence, The "Newport," Philadelphia, Pa.	A Oct. 27, 1891 M Dec. 16, 1891
SPARKS, CHAS. PRATT	Chief Engineer, The County of London Electric Lighting Co., Surrey, England.	A Mar. 22, 1901 M June 28, 1901
SPAULDING, HOLLON C.	Contracting Engineer, Sargent, Conant & Co., Equitable Bldg., Boston; residence, 15 Park Vale, Brookline, Mass.	A April 21, 1891 M June 20, 1894
SPERRY, ELMER A.	Electrical Engineer, 855 Case Ave., Cleveland, Ohio.	A April 19, 1892 M Feb. 21, 1893
SPRAGUE, FRANK J.	(*Past-President.*) Consulting Engineer, Sprague Electric Co., 20 Broad St.; residence, 305 West 86th St., New York City	A May 24, 1887 M Feb. 17, 1897

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Name.	Address.	Date of Membership.
SPRINGER, FRANK W.	Assistant Professor Electrical Engineering, University of Minn., Minneapolis, Minn	A Nov. 23, 1900 M Apr. 26, 1901
STANLEY, WILLIAM	Electrical Engineer and Inventor, Great Barrington, Mass.	A Dec. 6, 1887 M Oct. 26, 1898
STEARNS, CHARLES K., *E.E.*	Mechanical and Electrical Engineer, 93 Federal St., Boston; residence, 7 Vernon St., Brookline, Mass.	A Aug. 6, 1889 M May 16, 1893
STEARNS, JOEL W.	Treasurer. Mountain Electric Co., Box 1531, Denver, Col.	A June 20, 1894 M Nov. 20, 1895
STEBBINS, THEODORE	Engineer of Committee on Local Companies, General Electric Co., Schenectady, N. Y.	A July 9, 1889 M June 17, 1890
STEINMETZ, CHARLES P.	(*President.*) Electrician, General Electric Co., Schenectady, N. Y.	A Mar. 18, 1890 M April 21, 1891
STEPHENS, GEORGE	Societe des Etablissements Postel-Vinay, 219 Rue de Vangirard, Paris, France	A June 20, 1894 M Dec. 18, 1895
STEVENS, J. FRANKLIN	President Keystone Electrical Instrument Co., 9th St and Montgomery Ave.; Philadelphia Pa.	A Sept. 19, 1894 M Feb 28, 1901
STEWART, ROBERT STUART	Westinghouse Electric and Mfg., Co., 440 Jefferson Ave., Detroit, Michigan.	A Dec. 20, 1896 M May 15, 1900
STIERINGER, LUTHER	Electrical Expert, 129 Greenwich St., New York City.	A June 8, 1887 M Nov. 1, 1887
STILLWELL, LEWIS B.	Consulting Electrical Engineer, Electrical Director, Rapid Transit Subway Construction Co., Park Row Bldg., New York City.	A April 19, 1892 M Nov. 15, 1892
STORRS, PROF. H. A.	U. S. Assistant Engineer, Post Office Bldg.; residence, 45 William St., New London, Ct.	A Mar. 21, 1893 M Jan. 24, 1900
STOTT, HENRY G.	Supt. Motive Power, Manhattan Railway Co.; residence, 35 Mount Morris Park, West, New York City.	A Sept. 25, 1895 M April 22, 1896
STRONG, FREDERICK G.	Box, 959, Hartford, Conn.	A Oct. 27, 1891 M July 18, 1899
SWINTON, ALAN ARCHIBALD CAMPBELL.	Consulting Electrical Engineer, 66 Victoria St., London S. W. England.	A Mar. 22, 1901 M June 28, 1901
TERRY, CHARLES A.	Lawyer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A April 5, 1887 M May 17, 1887
THEBERATH, THEODORE E.	Supt. Yuba Division, Bay Counties Power Co., Marysville, Cal.	A Mar. 23, 1898 M June 24, 1898
THOMAS, BENJAMIN F.,	Professor of Physics, Ohio State University, Columbus, O.	A June 7, 1892 M Nov. 15, 1892
THOMSON, ELIHU	(*Past President*). Electrician, General Electric, and Thomson Electric Welding Companies, Lynn, residence, 22 Monument Ave., Swampscott, Mass.	A April 15, 1884 M April 21, 1891

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Name.	Address.	Date of Membership
THOMPSON, EDWARD P.	Solicitor of Patents, and Expert, 156 Fifth Ave., cor. 20th Street, residence, 1 Gramercy Park, New York City.	A April 15, 1884 M Dec. 3, 1889
THRESHER, ALFRED A.	Electrical Engineer and Proprietor Thresher Electric Co., Dayton, O	A April 22, 1896 M June 24, 1898
THURNAUER, ERNST	Manager, Thomson-Houston International Elec. Co., 27 Rue de Londres, Paris, France.	A Oct. 14, 1887 M Dec. 6, 1887
TISCHENDÖRFER, F.	Civil-Ingenieur, Elektrotechnisches Bureau, Ottostrasse 11, Berlin, N. W. Germany.	A April 19, 1892 M Nov. 21, 1894
TRAFFORD, EDWARD W.	Electrical Engineer, Richmond Passenger and Power Co., Foot of 7th St., Richmond, Va.	A Feb. 21, 1894 M Dec. 19, 1894
UEBELACKER, CHAS. F.	With Ford, Bacon & Davis, Hackensack, N. J.	A Feb. 7, 1890 M Nov. 15, 1893
UHLENHAUT, FRITZ, JR.	Consolidated Traction Co., *Times* Building, Pittsburg, Pa.	A May 7, 1889 M Dec. 19, 1894
UPTON, FRANCIS R	Edison Laboratory; residence, 20 High St., Orange, N. J.	A May 17, 1887 M Mar. 15, 1892
VANSIZE, WILLIAM B. [Life Member.]	Solicitor of Patents, Expert in Patent Cases, 253 Broadway, New York City; residence, 210 Lincoln Road, Flatbush, Brooklyn, N. Y.	A April 15, 1884 M Oct, 21, 1884
VAN TRUMP, C. REGINALD	Engineer and Manager, Wilmington City Electric Co., Wilmington, Del.	A Feb. 5, 1886 M Feb. 21, 1894
VARLEY, RICHARD JR.	President, the Varley Duplex Magnet Co., 138 7th Street, Jersey City; residence, Phillipsdale, R.I.	A April 25, 1900 M Feb. 28, 1901
WADDELL, MONTGOMERY	Consulting Engineer, 135 Broadway, New York City.	A Feb. 7, 1888 M May 1, 1888
WAIT, HENRY H.	Assistant Electrical Engineer, Western Electric Co., residence, 4919 Madison Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WALDO, LEONARD	Electrical Engineer, Room 1712, 49 Wall St., New York; residence, 640 West 8th St., Plainfield, N. J.	A June 5, 1888 M Dec. 4, 1888
WALKER, SYDNEY F.	Consulting Electrical Engineer, 12 Leinster Square, London W., Eng.	A June 2, 1885 M May 17, 1887
WALL, LOUIS JAMES BENARD	Full Partner, Splatt, Wall & Co., Perth, Western Australia.	A July 26, 1900 M Nov. 23, 1900
WARNER, ERNEST P.	Electrical Engineer, Western Electric Co.; residence, 402 Belden Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WATERMAN, F. N.	Mechanical and Electrical Engineer, 150 Nassau St., New York City.	A Feb. 21, 1893 M June 20, 1894
WEAVER, W. D.	(*Manager.*) Editor *Electrical World, and Engineer*; residence, Englewood, N. J.	A May 17, 1887 M May 17, 1887

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Name.	Address.	Date of Membership.
WEBB, HERBERT LAWS	18 Cortlandt St.; residence, 253 West 42d St., New York City.	A Oct. 21, 1890 M Dec. 16, 1890
WEBBER, CHARLES EDMOND	Major General, *C. B.* (ret.) *R. E.* Past President and Member of Council, Institution of Electrical Engineers, 17 Egerton Gardens, London, England.	A Jan. 9, 1901 M Jan. 24, 1902
WEEKS, EDWIN R.	Consulting Engineer, 606 New Nelson Building; Telephone, 409 and 245; residence, 3408 Harrison St., Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
WELLER, HARRY W.	Electrical Engineer, 202 St. James St., Montreal, P. Q.	A Oct. 21, 1890 M Nov. 24, 1891
WESTON, EDWARD	(*Past President.*) President, Weston Electrical Instrument Co., Waverly Park, Essex Co., N. J., and 645 High St., Newark, N. J.	A April 15, 1884 M Oct. 21, 1884
WETZLER, JOSEPH	President, The Electrical Engineer Institute of Correspondence Instruction, 240 W. 23d St.; residence, 257 W. 104th St., New York City.	A April 15, 1884 M Dec. 9, 1884
WHARTON, CHAS. J.	Palace Chambers, Westminster, London, Eng.	A Jan. 3, 1888 M May 1, 1888
WHEELER, SCHUYLER SKAATS, *Sc.D.* [Life Member.]	President, Crocker-Wheeler Co., 39 Cortlandt St., N. Y., and Ampere, N. J.; residence, 4 West 33d St., New York City.	A June 2, 1885 M Sept. 1, 1885
WHITE, JAMES GILBERT	J. G. White & Co., Electrical Engineers and Contractors, 29 Broadway, New York City.	A April 2, 1889 M May 15, 1900
WHITE, WILL F.	Electrical Engineer, General Manager The Cincinnati Edison Electric Co., 109 E. 5th St., Cincinnati, Ohio.	A Feb. 7, 1890 M July 27, 1898
WHITE-FRASER, GEO.	*Mem. Can. Soc. C. E.*; 18 Imperial Loan Building, Toronto, Ont.	A Sept. 22, 1891 M Dec. 18, 1895
WIENER, ALFRED E.	Chief Instructor, The Electrical Engineer Institute, 240 W. 23d St., New York; residence, 209 East 11th St., Brooklyn, N. Y.	A May 16, 1893 M May 15, 1894
WILCOX, NORMAN T.	Sup't Colorado Electric Power Co., Canon City, Col.	A May 21, 1895 M Jan. 22, 1896
WILLIS, EDWARD J.	President, Richmond Electric Co., 211 E. Franklin St., Richmond, Va.	A Nov. 30, 1897 M Feb. 28, 1900
WILLYOUNG, ELMER G.	E. G. Willyoung & Co., Electrical and Scientific Instruments, 11 Frankfort St., New York City.	A Nov. 24, 1891 M Dec. 20, 1893
WILSON, CHARLES H.	General Superintendent, American Telephone and Telegraph Co., 15 Dey St., New York City.	A Nov. 24, 1891 M Feb. 16, 1892
WILSON, FREMONT	Consulting Engineer, 80 Broadway, (Telephone, 4092 Cortlandt) New York City; residence, 10 Hamilton Ave., Yonkers, N. Y.	A Mar. 6, 1888 M June 5, 1888

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Name	Address.	Date of Membership.
WILSON, HARRY C.	Supt. of P. O. Telegraph with the Government, Kingston, Jamaica, West Indies.	A Jan. 19, 1891 M June 7, 1892
WILSON, HOWARD S.	Superintendent, Puebla Electric Light Co., Puebla, Mexico.	A Aug. 23, 1899 M Feb. 28, 1902
WINCHESTER, A. E.	Electrical Commissioner and General Supt., City of South Norwalk Electric Works, also Consulting Engineer for Municipalities residence, 4 Gerard Place, South Norwalk, Conn.	A June 8, 1887 M Nov. 1, 1887
WINSLOW, GEORGE HERBERT	Consulting Electrical Engineer, 339 Fifth Ave., Pittsburg, Pa.	A April 17, 1895 M Feb. 26, 1896
WOLCOTT, TOWNSEND	Electrician; residence, 329 Clinton St., Brooklyn, N. Y.	A Mar. 6, 1888 M Dec. 16, 1890
WOLVERTON, B. C.	Engineer, N. Y. & Pa. Telephone and Telegraph Co., Elmira, N. Y.	A Mar. 18, 1890 M Feb. 21, 1895
WOODWARD, WM. CARPENTER	Electrical Engineer, Narragansett Electric Lighting Co., 60 Weybosset St., residence, 5 Charles Field St, Providence, R. I.	A Nov. 18, 1896 M Apr. 25, 1902
WORDINGHAM, CH S. H.	Consulting Engineer, 19 Brasenose St., Manchester, England.	A July 27, 1898 M Oct. 26, 1898
WOTTON, JAMES A.	Manager Wotton Electric and M'f'g. Co. Box 543 Atlanta, Ga.	A Oct. 27, 1897 M Feb. 28, 1901
WRIGHT, PETER	President, Virginia Electric Company, Norfolk, Va.	A May 16, 1889 M Jan. 16, 1895
WURTS, ALEXANDER JAY	Manager Nernst Lamp Co., Pittsburg, Pa.	A April 19, 1892 M Nov. 15, 1892
YOUNG, C. GRIFFITH	Engineer Construction, J. G. White & Co., 29 Broadway, New York.	A Jan. 3, 1889 M April 21, 1891
YOUNG, WALTER DOUGLAS	Electrical Engineer B. & O. R. R., Roland Park, Baltimore, Md.	A Apr. 26, 1899 M Jan. 24, 1900

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Members, - - - - 403

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ASSOCIATES

Name.	Address.	Date of Election.
ABBOTT, HENRY	President, Calculagraph Co., 9 Maiden Lane, N. Y.; residence, 32 So. Clinton St., East Orange, N. J.	Apr. 28, 1897
ABBOTT, WILLIAM L.	Chief Operating Engineer, Chicago Edison Co., 139 Adams St.; residence, 3213 Becon St , Chicago, Ill.	Oct. 25, 1901
ABELLA, JUAN	Consulting Engineer, Buenos Aires and Belgrano Tramways Co.: residence, 691 Calle Bolivar, Buenos Aires, Argentine Republic.	Aug. 5, 1896
ADAMS, COMFORT A., JR.	Assistant Professor of Electrical Engineering, Harvard University, 13 Farrar St., Cambridge, Mass.	Jan. 17, 1894
ADAMS, ERNEST KEMPTON, *E.E.A.M.*	Electrical Engineer, 455 Madison Ave., New York City.	July 27, 1898
ADAMS, FRANK PIERCE	Electrician, Stockton Gas & Electric Co., residence, 329 E. Channel St., Stockton, Cal.	Feb. 15, 1899
ADAMS, JULIUS LE ROY	Chief Engineer, Hartford, Manchester & Rockville Tramway Co., Manchester, Conn.	Feb. 15, 1899
ADAMS, WILLIS LONGFELLOW.	General Manager, Adams Construction Co., Gluck Building; residence, 726 Buffalo Avenue, Niagara Falls, N. Y.	Jan. 24, 1902
ADAMSON, DANIEL	Manager Joseph Adamson & Co., Hyde, Cheshire, England.	Feb. 26, 1896
ADLER, ALPHONSE A.	F. J. & A. A. Adler, Electrical Engineers and Contractors, 123 Liberty St.; residence, 237 Eldridge St., New York City.	July 12, 1 00
AGNEW, CORNELIUS R.	18 William St.; residence, 23 West 39th St., New York City.	Mar. 21, 1894
ALBIN, HENRY ALLISON	General Manager and Electrical Engineer, Concord Street Railway, Concord, N. H.	Mar. 22, 1901
ALEXANDER, HARRY	Electrical Engineer, General Manager and Vice Prest. Alexander-Chamberlain Electric Co., 25 West 33rd St., and 18 and 20 W. 34th St., Telephone 3767–38th, New York City.	April 21, 1891
ALLAN, JOHN	Full Partner, H. H. Kingsbury & Co., 54 Margaret St., Sydney, N. S. W.	Dec. 28, 1898
ALLEN, ALBERT P.	General Inspector, American Tel. & Tel. Co., 15 Dey St.; residence, 44 Irving Place, New York City.	July 26, 1900
ALLEN, WYATT H.	Assistant Engineer, Benjamin, Hunt & Meredith, 331 Pine St., San Francisco, Cal.	Apr. 27, 1898
ALLEN, WALTER CUMMINGS,	Electrical Engineer of the Government of District of Columbia, District Building, residence, Victoria Flats, Washington, D. C.	June 24, 1898
ALVERSON, HARRY BARTLETT	Superintendent, Cataract Power and Conduit Co., 40 Court St., Buffalo, N. Y.	Oct. 25, 1901

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Name.	Address.	Date of Election
AMBLER, WILLIAM	Instructor, Cornell University, Ithaca, N. Y.; residence, 76 Lincoln Ave., Cleveland, Ohio.	July 12, 1900
AMSTUTZ, NOAH STEINER	Vice-President Amstutz Osborn Co., 716 Caxton Building; residence, 27 Hillsdale Ave., Cleveland, O.	Jan. 3, 1902
ANDERSON, DOUGLAS SMITH	Associate Professor of Electrical Engineering, Tulane University, New Orleans, La.	Apr. 26, 1901
ANDERSON, HENRY S.	General Manager and Electrician, United Electric Light Co., Springfield, Mass.	Jan. 16, 1895
ANDREWS, WILLIAM C.	*Electrical World and Engineer*, 114 Liberty St., New York, residence, Hotel Margaret, Brooklyn, N. Y.	May 21, 1895
ANTHONY, JAMES STOWELL	General Electric Co., 44 Broad St., New York City.	Apr. 25, 1902
APPLEYARD, ARTHUR E.	President, Natick Gas and Electric Co., Natick, Mass.	Aug. 5, 1896
ARCHBOLD, WM. K.	University Building, Syracuse, N. Y.	June 20, 1894
ARCHIBALD, ERNEST M.	Electrical Engineer, American Locomotive Co., Richmond Works, Richmond, Va.	May 15, 1900
ARCHER, GEO. F.	Electrical Engineer, 156 Madison Ave., New York City.	Nov. 21, 1894
ARMSTRONG, ALBERT H.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	June 24, 1898
ARMSTRONG, SAMUEL GEORGE	District Engineer, Grand Junction Railway, King Williamstown, Cape Colony, South Africa	Jan. 3, 1902
ARNOLD, CHESTER HASTINGS	Assistant Engineer New York Telephone Co., 18 Cortlandt St.; residence, 241 East 18th Street, New York City.	Jan. 3, 1902
ARNOLD, WARD S.	Electrical Engineer, Railway Department General Electric Co., Monadnock Building; residence, 384 E. 40th St., Chicago, Ill.	Jan. 24, 1902
AROZARENA, RAFAEL MAXIMO DE	Consulting Engineer, City of Mexico, Mexico.	Sept. 27, 1901
ASHE, SIDNEY WHITMORE	Assistant in Physics, Polytechnic Institute, Brooklyn; residence, Webster Avenue, Bedford Park, N. Y.	June 28, 1901
ASHLEY, FRANK M., *M.E.*	108 Fulton St., New York; residence, 172 Stuyvesant Ave., Brooklyn, N. Y.	Nov. 21, 1894
ATKINS, CHARLES GILMAN	Consulting Engineer, Pratt & Atkins, 1110 Monadnock Building, Chicago, Ill.	Oct. 25, 1901
ATKINS, HAROLD B.	Assistant to H de B. Parsons, Consulting Engineer, 22 William St., New York City.	June 23, 1897
ATKINSON, WILLARD S.	Electrical Engineer and Factory Manager, Zindars & Hunt, 127 Fifth Ave.; R.F.D. No. 51, New Brunswick, N. J.	Oct. 25, 1901
ATWOOD, GEORGE F.	With Western Electric Co., New York City; residence, 1030 Hudson St., Hoboken, N. J.	Sept. 16, 1890

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Name.	Address.	Date of Election
AUEL, CARL B.	Engineer. British Westinghouse Elec. & M'f'g Co., Ltd., East Pittsburg, Pa.	July 26, 1900
AUSTIN, SYDNEY B.	Consulting Engineer, 3912 Fifth Ave., Pittsburg, Pa.	Sept. 25, 1895
AVERRETT, ANDREW E.	Engineer, General Electric Co., Schenectady, N. Y,	Jan, 3, 1902
AYLMER-SMALL, C. SIDNEY	Assistant Engineer, Waldorf-Astoria, New York; residence, 15 Randolph St., Passaic, N. J.	Oct. 24, 1900
AYLSWORTH, J. WALTER	Experimenter and Chemist, Edison Laboratory; residence, 223 Midland Ave., East Orange, N. J.	Sept. 27, 1901
AYRES, ALBERT DOANE	Salesman Westinghouse E.& Mfg.Co., 71 La Salle St.; residence, 3803 Grand Boulevard, Chicago, Ill.	Feb. 28, 1902
BABSON, ARTHUR C.	Engineer, Portland Office, General Electric Co., Worcester Building, Portland, Oregon.	Mar. 28, 1900
BADEAU, ISAAC F.	General Electric Co.; residence, 144 Lafayette St., Schenectady, N. Y.	Feb. 26, 1896
BAILEY, LEON W.	Assistant Engineer, The Eddy Electric Mfg. Co., 8 Oliver St., Boston, Mass	Sept. 27, 1901
BAILEY, THEO. P.	Assistant Manager, Chicago Office, General Electric Co., 1047 Monadnock Building, Chicago, Ill.	Apr. 25, 1902
BAKER, ARTHUR O.	Superintendent, Wichita Gas, Electric Light and Power Co.; Box 574, Wichita, Kansas.	July 26, 1900
BAKER, JOSEPH B.	Consulting Electrical Engineer, 40 Lincoln St., Boston, Mass.	Sept. 27, 1901
BAKER, WILLIAM EDGAR	W. E. Baker & Co., Engineers, 170 Broadway, New York City.	June 28, 1901
BALCOME, HERBERT A.	With The B. F. Sturtevant Co., Jamaica Plain Station, Mass.	Oct. 27, 1897
BALDWIN, ALFRED DE V.	Selling Agent, Crocker-Wheeler Electric Co., P. O. Box, 267 ; residence, 206 W. 81 St., New York City.	Aug. 13, 1897
BALDWIN, GEORGE PORTER	John Martin & Co., 511 Douglass Building, Los Angeles, Cal.	Nov. 23, 1900
BALDWIN, JAS. C. T.	American Telephone and Telegraph Co., 125 Milk St.; residence, Chestnut Hill Ave., Boston, Mass.	April 17, 1895
BALL, HENRY PRICE	Electrical Engineer, General Incandescent Arc Light Co., 572 First Ave., New York City; residence, 66 So. Parsons Ave., Flushing, L. I.	May 21, 1901
BALL, WM. D.	Consulting Engineer, 614 Rookery Bldg, Chicago, Ill.	Nov. 20, 1895
BALLOU, WARREN JAMES	Electrician, Woonsocket Elec. Machine & Power Co., Station No. 2, Woonsocket, R. I.	Nov. 23, 1900
BALSLEY, ABE	Operating Superintendent, The Lachine Rapids Hydraulic & Land Co. Ltd., 160 McCord St., Montreal, Quebec.	Oct. 27, 1897

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Name.	Address.	Date of Election.
BAMBER, WILLIAM CHILDS	Electrical Engineer, Rapid Transit Subway Construction Co., 13 Park Row; residence, 60 W. 10th St., New York City.	Oct. 25, 1901
BANCROFT, CHAS. F.	Electrical Engineer, Massachussetts Electric Companies, 14 Kilby St., Boston, Mass.	Dec. 18, 1895
BANGS, CHAS. R.	Special Agent, American Telephone and Telegraph Co., 15 Dey St., New York City.	Jan. 26, 1898
BANKS, WILLIAM C.	Electrician, Gordon Battery Co., New York City.	May 18, 1897
BARNES, CHAS. R.	City Electrician and Electrical Expert to State R. R. Commission, Rochester, N. Y.	Aug. 13, 1897
BARNES, EDWARD A.	Electrical Expert, Fort Wayne Electric Co., Fort Wayne, Ind.	Sept. 20, 1893
BARNES, HOWELL HENRY	Beech Grove Inn, Pittsfield, Mass.	Feb. 28, 1900
BARNETT, CARL P.	Draftsman and Engineer, with S. & S. Packing Co., 41st St. and Ashland Ave., Chicago.	Jan. 25, 1901
BARON, MAX D.	Electrical Engineer and Contractor, 125 East 23d St.; residence, 61 East 75th St., New York City.	Mar. 28, 1900
BARR, FRANK ADELBUT	Manager and Electrician, Fries M'f'g. and Power Co., Winston-Salem, N. C.	Jan. 9, 1901
BARR, JOHN B.	Electrical Engineer, General Electric Co., 44 Broad St., New York City.	April 25, 1900
BARRY, DAVID	Electrician and Superintendent, Amherst Gas Co., Amherst, Mass.	Aug. 5, 1896
BARTON, ENOS M.	President Western Electric Co., Clinton and Congress Sts., Chicago, Ill.	July 12, 1887
BATES, FREDERICK C.	Electrical Engineer, General Electric Co., 44 Broad St., New York City.	Jan. 20, 1891
BATES, PUTNAM A.	Assistant Secretary, Crocker-Wheeler Co., Ampere, N. J.; residence, 113 W. 72d St., New York City.	Jan. 20, 1897
BAUGHER, E. C.	Resident Engineer, Westinghouse Elec. & M'f'g Co., c/o Tokata & Co., Tokio, Japan.	Nov. 22, 1899
BAUM, FRANK GEORGE	Stanford University, Cal	Nov. 22, 1899
BAUSCH, FREDERICK EMIL	Chief Engineer, Pittsburg Plate Glass Co., Crystal City, Mo.	June 28, 1901
BAYLEY, GUY LYNFIELD	Assistant Manager Engineering Department, The American Trading Co., No. 28 Yokohama, Japan.	Feb. 28, 1901
BAYNE, HOWARD	c/o Dr. M. I. Pupin, Electrical Engineering Dept., Columbia University; residence, Riverside Drive, cor. 108th St., New York City.	Sept. 27, 1901
BEAUMONT, CHAS. W.	Assistant with Frank B. Rae, 52 Broadway; residence, 275 W. 127th St., New York City.	Jan. 9, 1901
BEEBE, MURRAY C.	Nernst Lamp Co.; residence, Amber Club, Pittsburg Pa.	Jan. 26, 1898

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Name.	Address.	Date of Election.
BEHREND, BERNHARD A.	In charge Alternating Current Department Bullock Electric Mfg. Co. Norwood, O.	Jan. 24, 1900
BELL, ALONZO C.	Owner and Manager, Bell Electric Motor Co., 197 Wooster St.; residence, 83 East 116th St., New York City.	Sept. 27, 1901
BELL, ORA A.	Electrical Engineer, Western Electric Co., 463 West St., New York; residence, 352 West 117th Street, New York.	Aug. 5, 1896
BELLMAN, JOHN JACOB	Electrical Engineer and Treasurer, H. B Coho & Co., Incorporated. 149 Broadway; residence, 90 King St., New York, N. Y.	Dec. 28, 1898
BENNETT, EDWARD	Electrical Engineer, Nernst Lamp Co.; residence, 530 Sheridan Ave., Pittsburg, Pa.	Sept. 27, 1901
BENNETT, EDWIN H., JR.	Electrician and Engineer, Diehl & Co., Elizabethport, N. J., and 19 West 33d St., Bayonne, N. J.	June 20, 1894
BENNETT, JOHN C.	Electrician, General Electric Co., 44 Broad St. New York City.	Mar. 18, 1890
BENNETT, WILLARD S.	Engineering Department, The S. S. White Dental Mfg. Co., 25 Union Square, West, New York City; residence, 50 Charles Place, Elmhurst, N. Y.	Oct. 25, 1901
BENOLIEL, SOL. D., *B. S., E. E., A. M.*	General Manager, Roberts' Chemical Co., Niagara Falls, N. Y.	Oct. 21, 1896
BENTLEY, EDWARD M.	Patent Attorney and Expert, Temple Court, New York City.	May 21, 1901
BENTLEY, MERTON H.	Superintendent, 221 N. Scoville Ave., Oak Park, Ill.	Oct. 18, 1893
BERG, ERNST JULIUS	Engineer, General Electric Co.; Schenectady, N. Y.	Sept. 19, 1894
BERG, ESKIL	Electrical Engineer, Gen'l Electric Co., Schenectady, N. Y.	Nov. 20, 1895
BERGENTHAL, VICTOR W.	Western Sales Engineer, The Stanley Electric M'f'g. Co., 15 Monadnock Block, Chicago, Ill.	Jan. 9, 1901
BERRESFORD, ARTHUR W., *B.S., M.E.*	Supt., The Cutler-Hammer M'f'g. Co., 12th St. and St. Paul Ave., Milwaukee, Wis.	May 15, 1894
BEST, A. T.	Electrical Engineer, 703 Showers Ave., Harrisburg, Pa.	April 19, 1894
BETHELL, U. N.	General Manager, The New York Telephone Co., 15 Dey St., New York City.	Jan. 17, 1894
BETTS, HOBART D., *E. E.*,	Room 517, 141 Broadway, New York, N. Y.; residence, Englewood, N. J.	Aug. 5, 1896
BEVERIDGE, EDMUND WALTER	Assistant Engineer, P. W. D. Ghar Canals, Larkhana, Sind. India.	Jan. 24, 1900
BICKNELL, DANA EDWIN	Assistant in Inspection Dept., Western Electric Co., 57 Bethune St; residence, Lyndhurst, N. J.	June 28, 1901

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Name.	Address.	Date of Election
BIDDLE, JAMES G.	Electrical and Scientific Instruments, Stephen Girard Bldg., Philadelphia, Pa.; residence, 417 West Price St., Germantown, Pa.	Aug. 5, 1896
BIJUR, JOSEPH, *A. B.*, *E. E.* [Life Member]	210 Centre, St., Telephone, 3276 "Spring;" residence, 310 West 80th St., New York City.	May 15, 1894
BINDEMANN, HARRY OTTO FERDINAND	Electrical Engineer Union Electricitats Gesellschaft, 43 Dorotheen Str., Berlin, Germany.	Jan. 24, 1902
BLACK, CHAS. N.	Ford, Bacon & Davis, 149 Broadway; residence, 43 E. 57th St., New York City.	April 19, 1890
BLACK, HOWARD D.	With Blackall & Baldwin, 39 Cortlandt St.; house, 340 Manhattan Ave., New York, N. Y.	Sept. 15, 1897
BLACK, ROBERT GIVEN	Supt. The Chambly Mfg. Co., Richelieu Village, P. Q.	May 21, 1901
BLACKALL, FREDERICK, S.	P. O. Box, 267; office, 39 Cortlandt St.; residence, 51 Manhattan Ave., New York.	Sept. 15, 1897
BLACKWELL, FRANCIS O.	Engineer, Power and Mining Dept., General Electric Company, Schenectady, N. Y.	Mar. 28, 1900
BLACKWELL, HOWARD LANE	Assistant in Physics Harvard University, 13 Little's Block, Cambridge, Mass.; residence, East Orange, N. J.	Jan. 24, 1902
BLAKE, HENRY W.	Editor, *Street Railway Journal*, 114 Liberty St., New York City.	Nov. 13, 1888
BLAKE, THEODORE W.	Electrical Engineer, Goodyear Insulating Co., 1955 Park Ave.; residence. Engineers Club, 374 5th Ave., New York City.	Sept. 20, 1893
BLAKEMORE, MAURICE NEVILLE	Electrical Engineer, with Westinghouse E. & M. Co., Pittsburg; residence, 509 Pitt St., Wilkinsburg, Pa.	Jan. 25, 1901
BLANCHARD, CHARLES M.	Union League, Philadelphia, Pa.	Sept. 19, 1894
BLISS, LOUIS DENTON	Principal Bliss Electrical School, 614 12th Street, Washington, D. C.	July 12, 1900
BLISS, WILLIAM L., *B. S.*, *M. M. E.*	President, Bliss Electric Car Lighting Co., 16 Exchange Pl., New York City; residence, 505 Throop Ave., Brooklyn, N. Y.	Mar. 21, 1894
BLIZARD, CHARLES	Manager Sales Department Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia; residence, 409 West Price St., Germantown, Pa.	Nov. 21, 1894
BLUNT, WILLAM W.	Engineer, Westinghouse Electric and M'f'g Co., Ltd., Westinghouse B'ld'g, Norfolk St., Strand, W. C., London, Eng.	Dec. 16, 1896
BOGEN, LOUIS E.	Instructor in Physics, University of Cincinnati; residence, 547 Hale Ave., Avondale, Cincinnati O.	May 16 1899

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Name.	Address.	Date of Election.
BOGUE, CHARLES J.	Manufacturer of Search Lights and High Candle Power Focussing Arc Lamps, 213 Centre St., New York City.	Dec. 3, 1889
BOHM, LUDWIG K., *Ph.D.*,	Consulting Electrical and Chemical Expert, 320 Broadway, N. Y. City.	Nov. 15, 1892
BOLAN, THOMAS V.	Local Engineer, General Electric Co., 214 S. 11th St.; residence, 501 N. 40th St., Philadelphia, Pa.	Aug. 5, 1899
BOLLES, FRANK G.	Manager Advance Dept., Bullock Electric Mfg. Co., Cincinnati, O.; Wagner Eleccric Mfg. Co., St. Louis, Mo.	May 21, 1901
BONYNGE, PAUL	Attorney and Counsellor-at-Law firm of Latson & Bonynge, 141 Broadway, New York, residence, 261 Quincy Street, Brooklyn, N. Y.	May 16, 1899
BOWIE, AUGUSTUS JESSE, JR.	Engineer in charge Mechanical Department, Kern County Land Co., Bakersfield, Cal.	May 15, 1900
BOWMAN, JOSEPH H.	Resident Engineer, V. C. & P. R. R., Box 21, Cordola, Mexico.	May 16, 1899
BOYD, JOHN DUNCAN	Electrician, Standard Electric Co., Jackson, Cal.	Feb. 28, 1900
BRACKETT, BYRON B.	Instructor in Electricity, Rutgers College; residence, 106 Easton Ave., New Brunswick, N. J.	Nov. 30, 1897
BRACKETT, PROF. CYRUS F.	Princeton, N. J.	April 15, 1889
BRADDELL, ALFRED E.	Electrical Inspector, Underwriters' Association, Middle Department, 316 Walnut St., residence, 7435 Boyer St., Mt. Airy, Philadelphia, Pa.	Sept. 1, 1890
BRADY, NICHOLAS F.	Treasurer, The N. Y. Edison Co., 57 Duane St., New York City.	May 21, 1901
BRADY, PAUL T.	Manager, Central N. Y. Agency, Westinghouse Electric and Mfg. Co., Syracuse, N. Y.	July 12, 1887
BRAGG, CHARLES A.	Manager Phila. Agency, Westinghouse Electric and Mfg Co., 708 Land Title Building, residence, 3420 Powelton, Ave., Philadelphia, Pa.	Sept. 20, 1893
BRANDAO, JULIO VIVEIROS, *C. E.*	Rua Barao do Flamengo 8, Rio de Janeiro, Brazil, S. A.	Jan. 25, 1901
BRAUN, CHRISTIAN EDWARD	Draughtsman, Western Electric Co., New York City; residence, 223 Madison St., Brooklyn, N. Y.	Sept. 27, 1901
BRAYSHAW, J.	Telegraph Superintendent Great Southern Railway, City of Buenos Aires.	Aug. 5, 1896
BREWSTER, WALTER SCOTT	Electrician, Standard Underground Cable Co., 114 Rector St., Perth Amboy, N. J.	Apr. 26, 1901

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Name.	Address.	Date of Election.
BRIESEN, HAROLD V.	Engineering Department, American Telephone and Telegraph Co., 22 Thames St., New York City; residence, 80 Hackensack Ave., Weehawken, N. J.	June 28, 1901
BRISLEY, EDWARD BETTS	Student, Stevens Institute, Hoboken; residence, 102 W. 75th St., New York City.	Apr. 25, 1902
BRIXEY, W. R.	Proprietor and Manufacturer, Day's Kerite Wire and Cables, 203 Broadway, New York City.	Sept. 20, 1893
BROICH, JOSEPH	Superintendent and Electrician, with F. Pearce, New York City; residence, 1622 8th Ave. Brooklyn, N.Y.	Jan. 17, 1894
BROILI FRANK	Electrical Engineer, California Elec. Works; residence, 154 Hickory Ave., San Francisco, Cal.	Feb. 23, 1898
BROPHY, WILLIAM	Consulting Electrical Engineer, 17 Egleston St., Jamaica Plain, Mass.	Mar. 5, 1889
BROWD, PAUL K.	Chief Engineer, The Russian Electric Company, "Union." Box 188, Kiev., Russia.	Feb. 15, 1899
BROWN, BENJAMIN	Student, Polytechnic Institute; residence, 381 Sackett St., Brooklyn, N. Y.	June 28, 1901
BROWN, CHAS. L.	General Electrical Contractor, 312 Fisher Building, Chicago, Ill.	Nov. 20, 1895
BROWN, ELLIS EUGENE	Electrical Engineer, Philadelphia and Reading Railway Co., 7th and Franklin Streets, Reading, Pa.	May 16, 1899
BROWN, HUGH AUCHINCLOSS	Electrical Engineer, Ampere and Rutherford; residence, 285 Springdale Ave., East Orange, N.J.	Mar. 28, 1902
BROWN, HUGH THOMAS	Railways and Light Co. of America, 1500 Continental Trust Building, Baltimore, Md.	Jan. 26, 1898
BROWN, ROBERT G.	Electrician, 158 Montague St., Brooklyn, N. Y.	Oct. 25, 1901
BROWN, WARREN DAY	Electrical Engineer, The Auto-Electric Co., 61 Elm St; residence, 103 E. 39th St., New York City.	Jan. 25, 1901
BROWNE, WM. HAND, JR.	Asst. Professor of Electrical Engineering, The University of Illinois, Urbana, Ill.	April 25, 1900
BRUSH, FRED'K FARNSWORTH	Engineer, Societie Francaise Sprague, 6 Rue de Madrid, Parls, France.	Feb. 28, 1901
BUCKINGHAM, CHAS. L.	Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	April 15, 1884
BULL, ROBERT WILSON	Electrical Engineer, The New Jersey Zinc Co., (of Penn.,) Palmerton, Pa.	Mar. 22, 1901
BULLEN, DANA RIPLEY	General Electric Co., 200 Summer St., Boston; residence, Winthrop, Mass.	Mar. 28, 1902
BUNCE, THEODORE D. (20)	President, The Storage Battery Supply Co., 239 E. 27th St., New York City.	May 20, 1890

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Name.	Address.	Date of Election
BUNKER, ARTHUR CLIFFORD	Engineering Department, Stanley Electric Mfg. Co., 238 Crocker Building, San Francisco; residence, 1604 Central Ave., Alameda, Cal.	Oct. 25, 1901
BURDICK, IRVING EDWARD,	Treasurer and Engineer, Naval Electric Co., 256 Broadway; residence, 146 West 104 St., New York.	Oct. 24, 1900
BURKE, JAMES	Klopstack Strasse, 15; Berlin, Germany.	May 16, 1893
BURKETT, CHAS. WATSON	General Inspector, Southern Bell Tel. & Tel, Co., Atlanta, Ga.	Aug. 23, 1899
BURNETT, DOUGLASS, *B.S.*	The New York Edison Co., Inspection Dept., 55 Duane St., New York City; residence, 42 Livingston St., Brooklyn, N. Y.	Feb. 21, 1893
BURNETT, JAMES AUBREY	Draftsman and Designer, Royal Electric Co., 94 Queen St.; residence, 19 Shuter Street, Montreal.	Apr. 26, 1901
BURROUGHS, HARRIS S.	Member of firm of Ballantyne & Evans, Architects and Engineers, 20 Nassau St., New York City; residence, 1416 Pacific St., Brooklyn, N. Y.	Nov. 30, 1897
BURTON, PAUL G.	Switchboard Dep't. Western Electric Co.; residence, 475 Central Park, West, New York City.	Nov. 20, 1895
BUTLER, WILLIAM C.	President, The Puget Sound Reduction Co., Everett, Washington.	Mar. 21, 1893
BUYS, ALBERT	Electrical Engineer, The Rahway Electric Co., Pitman Grove, N. J.	Feb. 7, 1890
BYRNES, EUGENE A., *Ph.D.*	Principal Examiner Electro-Chemistry and Metallurgy U S. Patent Office, Washington, D. C.	May 21, 1901
BYRNS, ROBERT A.	Sales Manager, Metropolitan District, United Telpherage Co., 20 Broad Street, New York City.	Dec. 16, 1896
CABOT, FRANCIS ELLIOTT	Assistant Secretary and Electrician, Boston Board of Fire Underwriters, 55 Kilby Street Boston; residence, East Milton, Mass.	April 17, 1895
CABOT, SEWALL	Electrical Dept., New England Tel. & Tel Co., 101 Milk St, Boston; residence, High Street, Brookline, Mass.	Jan. 24, 1902
CALDWELL, EDWARD	Importer and Dealer, Technical Books and Periodicals, 112 Liberty St., New York City; residence, 50 Westervelt Ave., Plainfield, N. J.	Jan. 20, 1891
CALDWELL, EUGENE WILSON	Electrical Engineer, 315 Fifth Ave (Telephone, 205 Madison Sq.); residence, 20 E. 31st St., N.Y. City.	Jan. 24, 1902
CAMPBELL, HENRY ARTHUR	Electrician, Jamaica Electric Light & Power Co., Ltd., 38 Harbor St., Kingston, Jamaica.	Sep. 27, 1899
CANFIELD, MILTON C.	Electrical Engineer, 48 Greymont St., Cleveland, O.	Feb. 21, 1893
CANFIELD, MYRON E.	Western Electric Co.; residence, 404 W. 44th St. New York City.	May 21, 1895

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Name.	Address.	Date of Election.
CAPUCCIO, MARIO	Raimondo & Capuccio, Consulting Engineers and Patent Agents, Piazza Statuto 15, Turin, Italy.	Dec. 20, 1893
CARLTON, WILLARD GILBERT	Assistant to Chief Operating Engineer, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Oct. 25, 1901
CARNAGHAN, E. D.	In charge of machinery with Cipriano Guerrero. Durango, Do. Mexico.	July 26, 1900
CARPENTER, CHAS. E.	Vice-President, Carpenter Enamel Rheostat Co., Bronxville, N. Y.	Aug. 5, 1896
CARPENTER, HENRY CANNON	Assistant in Engineering Department, New York Telephone Co.; residence, 113 East 69th St., New York City.	Oct. 25, 1901
CARTER, FREDERICK WILLIAM *M. A.*,	With General Electric Co., Schenectady, N. Y.	Sept. 28, 1898
CARTY, JOHN J.	(*Manager*) Chief Engineer, New York Telephone Co., 15 Dey St., New York City; residence, Short Hills, N. J.	April 15, 1890
CASE, WILLARD E.	196 West Genesee St., Auburn, N. Y.	Feb. 7, 1888
CASSIDY, JOHN	Superintendent Mutual Telephone Co., Honolulu, Hawaiian Islands, U.S.A.	Nov. 23, 1898
CHAPMAN, A. WRIGHT	160 Hicks St., Brooklyn, N. Y.	Mar. 25, 1896
CHAPPELL, WALTER E. [Life Member.]	Engineer, Macartney, McElroy & Co., Ltd., 53 Victoria St., London, S.W. Eng.: Superintendent Overhead Construction Companhia Carris Ferro de Lisbon, 138 Avenida don Carlos, Lisbon, Portugal.	May 16, 1899
DE CHATELAIN, MIKAIL ANDREJEVITCH	Prof. of Electrical Engineering, Mining Institution and Electro-Technical Institution, Wasily Ostrow, 10 line No. 5, St. Petersburg, Russia.	Nov. 23, 1900
CHENEY, FREDERICK A.	Box 188, St. Catharines, Ont.	Oct. 1, 1889
CHESTER, M. E.	Telephone Engineer, Western Electric Co., 463 West St.; residence, 296 Manhattan Ave., N. Y City.	Feb. 28, 1902
CHILDS, SUMNER W.	Engineer, Kalgoorlie Electric Tramways Co., Kalgoorlie, Western Australia.	May 15, 1894
CHUBBUCK, LEONARD BURROWS	Checker in draughting room, Westinghouse E. & Mfg. Co.; residence, (Homewood) 535 Clawson St., Pittsburg, Pa.	Mar. 28, 1902
CLARK, CHAS. M., *E. E.*,	Clark & MacMullen, 20-22 Broad St., New York City.	April 22, 1896
CLARK, EUGENE BRADLEY	Electricical Engineer, Illinois Steel Co.; residence, 5342 Cornell Ave., Chicago, Ill.	Mar. 28, 1902
CLARK, FARLEY GRANGER	Electrician in charge 96th St. Power Station, Metropolitan St. Ry. Co., 96th St. and 1st Ave.; residence, 454 Manhattan Ave., New York City.	Apr. 26, 1901
CLARK, LEROY, JR.	Assistant General Manager, Safety Insulated Wire and Cable Co., 229 West 28th St.; residence, 72 West 52d St., New York City.	May 15, 1894

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Name.	Address.	Date of Election.
CLARK, WALLACE S.	Engineer, Wire, Cable and Tube Department, General Electric Co.; residence, 13 Front St., Schenectady, N. Y.	April 25, 1902
CLARK, WM. EDWIN	Partner Clark & Mills, Engineers and Contractors, 543 Boylston St., Boston and 1400 Mass. Ave., Cambridge; residence, 59 Brattle St., Cambridge, Mass.	Aug. 23, 1899
CLARK, WILLIAM J.	General Manager, Foreign Dept. General Electric Co., 44 Broad Street, New York City.	April 22, 1896
CLEMENT, EDWARD E.	Patent Attorney and Electrical Expert, McGill Building, 908 G. St., N.W.; residence, 2905 13th St., N. W., Washington, D. C.	May 18, 1897
CLEMENT, LEWIS M.	Haywards Almeda Co., Cal.	April 21, 1891
CLIFT, ARTHUR S.	Chief Mechanical Engineer, Siemens Bros. & Co., Lt d., Woolwich, Kent, England.	Sept. 27, 1901
CLOUGH, ALBERT L.	Box 114, Manchester, N. H.	Feb. 21, 1894
CODMAN, JOHN STURGIS,	Consulting Engineer. Associated with R. S. Hale, 31 Milk St.; residence, 57 Marlborough St., Boston, Mass.	Feb. 15, 1899
CODY, L. P.	Manager and Engineer, Grand Rapids Electric Co., 9 South Division St., Grand Rapids, Mich.	Aug. 5, 1896
COFFIN, CHAS. A.	General Electric Co., 44 Broad St., New York City.	Dec. 6, 1887
COGHLIN, JOHN P.	Electrical Engineer and Contractor, Page Electric Co., 24 Pearl St., Worcester, Mass.	Sept. 27, 1901
COHO, HERBERT B.	New York Manager Eddy Elec. Mfg. Co., 149 Broadway, New York City, residence, Mt. Vernon, N. Y.	Mar. 21, 1894
COLE, WM. HOWARD	Engineer, Carris de Ferro de Lisbon, Santo Auraro, Lisbon, Portugal.	April 25, 1900
COLE, WILLIAM WEEDEN	Vice-President and General Manager Elmira Water, Light and R. R. Co., Realty Building, Elmira, N. Y.	April 25, 1902
COLEMAN, WALTER H.	Supt. and Treasurer, Andover Electric Co., Andover, Mass.	Sept. 28, 1898
COLES, EDMUND P.	Local Engineer, General Electric Co., 214 S. 11th St., Philadelphia, Pa.	Oct. 23, 1895
COLLETT, SAMUEL D.	Eastern Manager, Elevator Supply and Repair Co., 136 Liberty St., New York City; residence, 134 Montague St., Brooklyn, N. Y.	Feb. 26, 1896
COLLINS, ARCHIE FREDERICK	Electrical Engineer and Inventor, Collins Wireless Telephone and Telegraph Co., 132 South 6th St., Philadelphia; residence, Narberth, Pa.	June 28, 1901
COMPTON, ALFRED G.	Professor of Applied Mathematics, College of the City of New York, 17 Lexington Ave.; residence, 40 W. 126th St., New York City.	Nov. 1, 1887

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Name.	Address.	Date of Electron.
CONKLIN, OLIVER FRANCIS	Consulting Electrical Engineer, The Robbins & Myers Co., Springfield, Ohio.	Oct. 25, 1901
CONVERSE, V. G.	President and General Manager of the Converse Transformer Co., 15th St. and Liberty Ave., Pittsburg, Pa.	Nov. 23, 1900
COOK, EDWARD JEROME	Electrical Engineer, Cleveland City Railway Co., Western Reserve Bldg.; residence, 66 Commonwealth Ave., Cleveland, O.	May 15, 1900
COOKE, GEORGE A.	Electrical Engineer, Westinghouse Electric and Mfg. Co., 323 S. Main St., Los Angeles, Cal.; residence, Chicago, Ill.	Mar. 22, 1901
COOPER, WILLIAM	General Superintendent, Bullock Electric Mfg. Co., Cincinnati, Ohio.	Feb. 28, 1902
COPELAND, CLEM. A.	Office Edison Electric Co., 2822 Key West St., Los Angeles, Cal.	June 23, 1897
COREY, FRED BRAINARD	Engineer, General Electric Co.; residence 3 High St., Schenectady, N. Y.	Dec. 20, 1893
CORNELL, JOHN B.	Niles-Bement-Pond Co., 136 Liberty St., New York City.	Sept. 25, 1895
CORSON, WILLIAM R. C.	Consulting Electrical Engineer, 440 Capitol Ave., Hartford, Conn.	Jan. 17, 1893
CORY, CLARENCE L.	Professor of Electrical Engineering, University of California, Berkeley, Cal.	April 19, 1892
COSBY, FRANK CLARK	Salesman, Westinghouse Elec. & Mfg. Co., 120 Broadway; residence, 124 West 114th St., New York City.	Mar. 28, 1902
COSGROVE, JAMES FRANCIS	38 St. Andrews Place, Yonkers, N.Y.	Nov. 23, 1898
COWEN, JULIAN BETTY,	Manager of Export Department, General Incandescent Arc Light Co., 572 First Ave.; residence, 204 W. 119th St., New York City.	Feb. 28, 1902
CRAIN, JOHN JAY,	2000 H St., N. W., Washington, D. C.	Dec. 16, 1896
CRANDALL, CHESTER D.	Assistant Treasurer, Western Electric Co., 259 South Clinton St.; residence, 2821 Sheridan Road Chicago, Ill.	Sept. 27, 1892
CRANE, W. F. D.	Electrical and Mechanical Engineer, Sanderson & Porter, 31 Nassau St., New York City; residence, 24 Reynolds Terrace, Orange, N. J.	Feb. 7, 1888
CRAVATH, JAMES RALEY	Western Editor, *Electrical World and Engineer*, 1139 Monadnock Block, Chicago, Ill.	Nov. 23, 1901
CRAWFORD, DAVID FRANCIS	Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Sept. 25, 1895
CREAGHEAD, THOMAS J.	President and General Manager, Creaghead Engineering Co., 802 Plum St., Cincinnati, O.	Sept. 20, 1893
CREHORE, ALBERT C., *Ph.D.*	The Crehore-Squier Intelligence Transmission Co., Brookside Park, Tarrytown, N. Y.	Dec. 21, 1892

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Name.	Address.	Date of Election.
CROCKER, EBEN CLINCH	Electrical Engineer, American Ordnance Co., 29 Harriet Street, Bridgeport, Conn.	Jan. 26, 1898
CROSBY, OSCAR T.	Potomac Light and Power Co., 1417 G Street, Washington, D. C.	Mar. 18, 1890
CROSSMAN, GILBERT	Telephone Engineer, Western Electric Co., 463 West St.; residence, 80 Washington Square E., New York City.	Nov. 22, 1901
DE CROW, CHARLES EDWARD	In charge of Power Apparatus, Output Dept., Western Electric Co., 242 S. Jefferson St.; residence, 996 Flournoy St., Chicago, Ill.	Sept. 27, 1901
CROWELL, ROBINSON	Assistant Electrician, Sacramento Electric Gas and Railway Co, Sacramento, Cal.	Dec. 28, 1898
CROZIER, ARTHUR BERTRAM	Draughtsman and Engineer, Schwarzchild & Sulzberger Packing Co., 45th St. and First Ave., New York City.	Jan. 9. 1901
CUMNER, ARTHUR B.	251 So. 12th St., Philadelphia, Pa.	Feb. 27, 1895
DACUNHA, MANOEL IGNACIO	Manager of the Electrical Section, Emprera Industrial Gram-Para, Para, U. S. of Brazil.	May 16, 1893
CUNNINGHAM, E. R.	Des Moines City Railway Co., 607 Mulberry St., Des Moines, Iowa.	Jan. 22, 1896
CUNNINGHAM, RICHARD H.	Demonstrator of Physiology, Columbia University, New York City.	May 21, 1901
CUNTZ, JOHANNES H.	325 Hudson St., Hoboken, N. J.	Mar. 5, 1889
CURRIE, N. M.	Santiago, Chili.	Feb. 15, 1899
CUTLER, JAMES ELMER	Manager of Philadelphia Office Stanley Electric M'f'g Co., 26 So. 15th St.; residence, Overbrook, Philadelphia, Pa.	Apr. 25, 1902
DAGGETT, ROYAL BRADFORD	Electrical Engineer, Electric Storage Battery Co., 43 Nevada Block, San Francisco, Cal.	Jan. 25, 1899
DAMON, GEO. A.	Electrical Engineer, Arnold Electric Power Station Co., 1540 Marquette Building, Chicago, Ill.	Jun. 24, 1898
DAMON, GEO. B.	[Address unknown.]	June 23, 1897
DANIELSON, ERNST	Technical Director, Allmänna Svenska Elektriska, A. B., Westeras, Sweden.	June 27, 1895
DARLING, EDWARD ALBERT	Engineer, Edison Portland Cement Co., Stewartsville, N. J.	Sept. 27, 1901
DASSORI, FREDERICK HUMBERT	Engineering Dept., N. Y. & N. J. Telephone Co., 81 Willoughby St.; residence, 12th Ave. cor. 84th St., Dyker Heights, Brooklyn, N.Y.	May 21, 1901
DATES, HENRY B.,	Professor of Electrical Engineering and Physics, Clarkson School of Technology, Potsdam, N. Y.	Dec. 28, 1898
DAVENPORT, GEORGE W.	Residence, 44 Bay St., Winchester, Mass.	June 4, 1889
DAVIDSON, EDW. C.	Patent Lawyer, 141 Broadway, New York City.	Feb 7, 1890

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Name.	Address.	Date of Election.
DAVIS, DELAMORE L.	Superintendent, Salem Electric Light and Power Co., 299 Lincoln Ave., Salem, O.	April 2, 1889
DAVIS, LESLIE FOSTER	Secretary and Manager, Jamaica Electric Light & Power Co., Ltd. 38 Harbor St., Kingston, Jamaica	Sept. 27, 1899
DAVIS, JOSEPH P.	Engineer, American Telephone and Telegraph Co., 113 W. 38th St., New York City.	April 15, 1884
DAVIS, PHILIP W.	Engineer of New England Office, The Electric Storage Battery Co., Boston; residence, 110 Irving Street, Cambridge, Mass.	May 15, 1900
DAVIS, W. J., JR.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 20, 1895
DAWSON, JOSIAH	Contractor for Electric Light and Power, etc , Cuba Street Extension, Wellington, New Zealand.	Jan. 9, 1901
DEAN, WALTER CLARK	Electrical Draughtsman in charge Equipment Department, Norfolk Navy Yard; residence, 131 Duke St., Norfolk, Va.	Sept. 27, 1901
DEEDS, EDWARD ANDREW,	President Board of Engineers, The Natural Food Co.; residence, 527 Riverside, Niagara Falls, N. Y.	Nov. 23, 1900
DEGEN, LEWIS	324 Stuyvesant Ave., Brooklyn, N. Y.	Sept. 25, 1895
DEMPSTER, THOMAS	Electrical Engineer, General Electric Co., Schenectady, N. Y.	May 17, 1898
DICK, WILLIAM AMZI	Designing Electrical Engineer, Westinghouse E. & M. Co., Pittsburg, Pa.	Mar. 28, 1902
DICKERSON, E. N.	Attorney-at-Law, 141 Broadway; residence 64 E. 34th St., New York City.	April 15, 1884
DIETERICH, FRED. G.	Solicitor of Patents and Mechanical Expert, 602 F Street, Washington, D. C.	July 18, 1899
DINKEY, ALVA C.	Supt. Electric Dept., Homestead Steel Works, Munhall, Pa.	Feb. 17, 1897
DIXON, JAMES	Electrical Engineer, Gray National Telautograph Co , Room 142, 80 Broadway, New York City; residence, 241 Franklin Place, Flushing, N. Y.	Jan. 24, 1902
DOBBIE, ROBERT S.	Electrical Engineer, Riding Mill-on-Tyne, Northumberland, Eng.	Feb. 5, 1889
DODD, SAMUEL THOMSON	Engineer Railway Department, Stanley Electric Mfg. Co., Pittsfield, Mass.	Sept. 27, 1901
DOHERTY, HENRY L.	40 Wall St., New York City.	Sept. 28, 1898
DONALDSON, WM. W.	Electrical Engineer, The Gould Storage Battery Co., 25 W. 33d St., New York City.	May 21, 1901
DOOLITTLE, CLARENCE E.	Manager and Electrician, Roaring Fork Electric Light and Power Co., Aspen, Colo.	May 15, 1894
DOOLITTLE, THOMAS B.	Engineering Department, American Telephone and Telegraph Co., 125 Milk St., Boston, Mass.	May 16, 1893

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Name.	Address.	Date of Election
DOPP, WILLIAM HUGH	Drawing-Room Foreman, Eddy Electric Mfg. Co., Windsor, Conn.	Sept. 27, 1901
DOREMUS, CHARLES AVERY	*M.D. Ph.D.* 59 W. 51st St., New York City.	July 7, 1884
DOUBT, THOMAS EATON	Professor of Physics and Electrical Engineering, The University of Washington, Seattle, Wash.	Jan. 9, 1901
DOUD, CHARLES HAMILTON	Student Columbia University, 30 W. 44th St., New York City.	Sept. 27, 1901
DOWIE, HORACE	With Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City.	Jan. 25, 1901
DOWNES, LOUIS, W.	Vice-President and General Manager, The D. & W. Fuse Co., 407 Pine St., Providence, R. I.	Nov. 22, 1899
DOWNING, P. M.	Manager Colusa Gas and Electric Co., Colusa, Colusa Co., Cal.	June 24, 1898
DRESSEL, JOHN HATHAWAY	With Wagner Electric Mfg. Co. of St. Louis, Mo.; Kane, Ill.	Sept. 27, 1901
DRESSER, CHARLES A.	Supt., Kohler Bros., 1808 Fisher Bldg., Chicago, Ill.	May 21, 1901
DRESSLER, CHARLES E.	17 Lexington Ave., New York City.	Dec 16, 1890
DROHAN, T. E.	Supt. of Shops, Northern Electric Mfg. Co., Madison, Wis.	May 21, 1901
DRYSDALE, DR. W. A.	Consulting Electrical Engineer, 414 Hale Building, Philadelphia, Pa.	Sept. 19, 1894
DRYER, ERWIN	Salesman and Engineer, Westinghouse E. & Mfg. Co.; residence, 171 La Salle St., Chicago, Ill.	Feb. 28, 1902
DUBOIS, TUTHILL,	Electrical Contractor, 19 Park Place; residence, 168 Linwood Street, Brooklyn, N. Y.	Aug. 23, 1899
DUNCAN, JOHN D. E. [Life Member.]	Engineer, with Sanderson and Porter, 31 Nassau St., New York City.	Mar. 20, 1895
DUNCAN, THOMAS	General Supt., Duncan Electric Mfg. Co., Lafayette, Ind.	Oct. 17, 1894
DUNN, CLIFFORD E.	Patent Attorney, Park Row Bldg, New York City, residence, 12-a Monroe St., Brooklyn, N. Y.	Feb. 15, 1899
DUNN, KINGSLEY G.	With C. C. Moore & Co., 218 Second Ave., So. Seattle, Washington.	Oct. 17, 1894
DURANT, EDWARD	Chief Electrical Engineer, Manhattan State Hospital of the State of New York, Ward's Island, N. Y.; residence, 115 East 26th St., New York City.	Nov. 15, 1892
DURANT, GEO. F.	General Manager Bell Telephone Co., of Mo., Telephone Building, St. Louis, Mo.	April 15, 1884
DUSINBERRE, GEORGE BROWN	Assistant to Fourth Vice-President Westinghouse Electric & Mfg. Co., Pittsburg; residence, Edgewood Park, Pa.	Nov. 22, 1901

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Name.	Address.	Date of Election.
DYER, ERNEST I.	Engineer and Manager of the Engineering Department of the American Trading Co., Box 28, Yokohama, Japan.	Jan. 25, 1899
DYER, SHUBAEL ALLEN	Manager Supply Dept. Mexican General Electric Co., Box 403, Mexico City, Mexico.	May 15, 1900
DYKE, OWEN ARTHUR WYNNE	Electrical Contractor, 30 St. George's St.; P. O. Box 811, Capetown, South Africa.	Sept. 27, 1901
DYSTERUD, EMIL	Superintendent and General Manager, Compania de Luz Electrica y Fuerza Motriz, Monterey, Nuevo Leon, Mexico.	July 26, 1900
EASTMAN, GEORGE NIAL	In charge of Testing Laboratory, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Nov. 22, 1901
EDDY, H. C.	Electrical Engineer, Lees Building, Chicago, Ill.	June 20, 1894
EDDY, HORACE T.	Assistant Prof. of Electrical Engineering, Union College, Schenectady, N. Y.	May 21, 1901
EDMANDS, I. R.	Superintendent, Union Carbide Co., Sault Ste Marie, Mich.	June 23, 1897
EDMANDS, SAMUEL SUMNER	Dept. of Science and Technology, Pratt Institute, Brooklyn, N. Y.	Mar. 22, 1901
EDMONSTON, EDGAR DAVIS	Electrical Engineer, The Lackawanna Iron and Steel Co., 401 Delaware Ave., Buffalo, N. Y.	Apr. 25, 1902
EDWARDS, JAMES P.	Consulting Electrician, Augusta; residence, Montesano, Summerville, Ga.	April 19, 1892
EDWARDS, CLIFTON V.	Attorney-at-Law and Solicitor of Patents, 220 Broadway, New York.	Nov. 22, 1899
EGLIN, JAMES MEIKLE	Chief of Electric Dept. Edison Electric Light Co., of Philadelphia, 10th and Sansom Sts.; residence, 4230 Chester Ave., Philadelphia, Pa.	July 26, 1900
EGLIN, WM. C. L.	Electrical Engineer, N. E. cor 10th and Sansom Sts., residence, 235 S. 42d St., Philadelphia, Pa.	Sept. 19, 1894
EHRET, CORNELIUS DALZELL	1011 Chestnut St., Philadelphia, Pa.	Jan. 24, 1902
EKSTRAND, CHARLES	Superintending Engineer, Brooklyn Cooperage Co., Brooklyn Elevator and Milling Co., and Palmer's Docks, North 6th St. and Kent Ave; residence, 74 South 9th St., Brooklyn, N. Y.	Apr. 25, 1902
EKSTROM, AXEL	Electrical Engineer, General Electric Co., Bangalore, India.	June 17, 1890
ELLARD, JOHN W.	J. L. Blackwell & Co., 229 East German St., Baltimore, Md.	June 23, 1897
ELIAS, ALBERT B.	1310 Washburn Street, Scranton, Pa.	Jan. 26, 1898

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Name.	Address.	Date of Election.
ELLINGER, EDGAR	Electrical Engineer, George A. Fuller Co., 137 Broadway; residence, 215 E. 79th St., New York City.	Apr. 25, 1902
ELLIOTT, ELMER G.	American Smelting and Refining Co.; residence, "The Manitou", Salt Lake City, Utah.	May 21, 1901
ELLIS, JOHN	Manager, The Lonsdale Co.'s Electric Light Plant, Lonsdale, R. I.	Apr. 26, 1899
ELLIS, R. LAURIE	Supt., Meridian Street Railway and Power Co., Meridian, Miss.	April 26, 1899
ELMER, WILLIAM, JR.	Assistant Master Mechanic, Altoona Machine Shop, Altoona, Pa.	Mar. 18, 1890
ELY, WM. GROSVENOR, JR.	Ass't Supt. Construction, General Electric Co., 849 Union Street, Schenectady, N. Y.	Mar. 21, 1893
EMERICK, LOUIS W.	Vice-President and General Manager, Fulton Light, Heat & Power Co.; residence, 189 First St., Fulton, N.Y.	Aug. 13, 1897
ENTZ, JUSTUS BULKLEY	Electrical Engineer, Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia, Pa.	Jan. 7, 1890
ERICKSON, F. WM.	Electrical Engineer, The Erickson Electric Equipment Co., 71 Federal St., Boston, Mass.	Sep. 19, 1894
ERWIN, FRANK BENNETT	Electrical Engineer, Westinghouse E. & M. Co., Pittsburg; residence, 515 Jeannette St., Wilkinsburg, Pa.	Jan. 3, 1902
ESTERLINE, J. WALTER	Instructor Electrical Engineering, Purdue University, residence, 401 State St., Lafayette, Ind.	Mar. 28, 1900
ESTES, ORANGE A.	Central Union Telephone Co., Columbus; residence, Ravenna, Ohio.	Jan. 3, 1902
ESTY, WILLIAM	Assistant Professor of Electrical Engineering, Lehigh University, South Bethlehem; residence, 129 Wall St., Bethlehem, Pa.	Mar. 20, 1895
ETHERIDGE, LOCKE	Pullman Car Works, Pullman; residence, 44 E. 50th St., Chicago, Ill.	Oct. 17, 1894
EVANS, CLEMENT W.	Electrical Engineer, American Engineering Co., Box 2100 Mexico City.	Feb. 28, 1900
EVANS, PAUL H.	Chief Engineer, Mexican General Electric Co., Apartado 403 Mexico City.	Jan. 24, 1900
EVERIT, EDWARD HOTCHKISS	Superintendent of Equipment, The So. N. E. Telephone Co., 641 Whitney Ave., New Haven, Conn.	Jan. 3, 1902
EYRE, MANNING K.	Buckeye Electric Co., Cleveland, O.	Oct. 17, 1894
FARNSWORTH, ARTHUR J.	Asst. Chief Engineer, Consolidated Railway, Electric Lighting and Equipment Co., 22 Thames Street, New York City.	Jan. 16, 1895
FARRAND, DUDLEY	General Manager, United Electric Company of New Jersey, 207 Market St.; residence, 141 Clinton Ave., Newark, N. J.	July 26, 1900

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Name.	Address.	Date of Election.
FERGUSON, LOUIS ALOYSIUS	General Superintendent, Chicago Edison Co., 139 Adams St., Chicago, Ill.; residence, 1401 Davis St., Evanston, Ill.	Oct. 25, 1901
FERGUSON, SAMUEL	Engineer, General Electric Co., Schenectady, N. Y.	Jan. 3, 1902
FERRIS, ROBERT MURRAY, JR.	Engineering Department, The N. Y. & N. J. Telephone Co., 81 Willoughby Street, Brooklyn, N. Y.; residence, 239 West 103d St, New York City.	Feb. 28, 1902
FIELDING, FRANK E. [Life Member.]	Chemist and Assayer, Virginia City, Nev.	Sept. 6, 1887
FINNEY, JOHN C.	Room 1121, Herman Building; residence, 34 Prospect Ave., Milwaukee, Wis.	Dec. 28, 1898
FIRTH, WM. EDGAR	Chief Engineer, The Midvale Steel Co., Nicetown, Philadelphia; residence, 7203 Boyer St., Germantown, Pa.	Mar. 25, 1896
FISH, FRED ALAN	Assistant Prof. of Electrical Engineering, Ohio State University, residence, 229 W. 11th Ave., Columbus, O.	Mar. 28, 1900
FISH, FREDERICK PERRY	President, American Telephone & Telegraph Co., 125 Milk St., Boston; residence, Brookline, Mass.	Mar. 28, 1902
FITZGERALD, THOMAS, JR.	Superintendent, F. & C. E. R. R. Co., Fairmount, W. Va.	Jan. 3, 1902
FITZHUGH, WM. H.	Supt. Bay City Electric Plant, Bay City, Mich.	April 27, 1898
FLATHER, JOHN J.	Professor of Mechanical Engineering, University of Minnesota; residence, 1103 Fourth St., S. E., Minneapolis, Minn.	April 19, 1892
FLEMING, JOHN BRECKENRIDGE, *M. M.*,	and Elec. Engineer, Bingham Consolidated Mining and Smelting Co., Bingham, Utah.	April 27, 1898
FLEMING, JOHN F.	Electrical Contractor, Brookline, Mass.	July 12, 1900
FLEMING, RICHARD	Designing Engineer, General Elec. Co., Lynn; residence, Swampscott, Mass.	Jan. 24, 1902
FLIESS, ROBERT ANTON	44 Chestnut St., East Orange, N. J.	Mar. 23, 1898
FLOY, HENRY	Consulting Electrical and Mechanical Engineer, 220 Broadway, New York City; residence, 17 Hawthorne Ave., East Orange, N. J.	May 17, 1892
FOG, CARL F.	Electrician, General Electric Co., Lynn; residence, East Saugus, Mass.	Mar. 28, 1900
FOLK, FREDERICK JACKSON.	Chief Electrician, New York & Queens E. L. & P. Co.; residence, 135 Rutland Rd., Brooklyn, N. Y.	Mar. 28, 1902
FOOTE, THOS. H.	Electrical Engineer, 84 So. Marengo Ave., Pasadena, Cal.	April 21, 1891

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Name.	Address.	Date of Election.
FORBES, FRANCIS	Lawyer, 32 Nassau St., New York City.	Sept. 16, 1890
FORD, ARTHUR HILLYER, *E. E.*	Prof. of Physics and Electrical Engineering, Georgia School of Technology, Atlanta, Ga.	Mar. 24, 1897
FORD, FRANK R., *M. E.*	Consulting Engineer, Ford, Bacon & Davis, 149 Broadway, New York City.	Mar. 25, 1896
FORD, WM. S.	Assistant to Chief Engineer, The American Telephone and Telegraph Co., room 73, 125 Milk St. Boston, Mass.	June 7, 1892
FOWLER, GEO. W.	Electrical Expert, The C. & C. Electric Co., Garwood, N. J.	Oct. 24, 1900
FRANCISCO, M. J.	President and General Manager, Rutland Electric Light Co., Rutland, Vt.	June 17, 1890
FRANK, GEO. WILLIAM	Engineer in charge Yadkin River Hydraulic Development, New London, N. C.	Sept. 28, 1898
FRANKENFIELD, BUDD	Instructor in Electrical Engineering, University of Wisconsin, 609 Lake St., Madison, Wis.	Feb. 17, 1897
FRANKLIN, W. S.	Professor of Physics and Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Jan. 22, 1896
FRANTZEN, ARTHUR	Electrical Engineer and Contractor, 225 Dearborn St., residence, 662 N. Irving Ave., Chicago, Ill.	Feb. 21, 1894
FRASER, JAMES WM.	438 Franklin Ave., Wilkinsburg, Pa.	May 21, 1901
FRENCH, THOMAS, JR., *Ph.D.*	114 N. Ingalls St., Ann Arbor, Mich.	Sept. 20, 1893
FREUDENBERGER, WILLIAM KAISER	Chief Electrician, The Colorado Fuel and Iron Co.; residence, 209 E. Evans, Pueblo. Col.	Nov. 22, 1901
FRIEDLAENDER, EUGENE	Electrician, Carnegie Steel Company, Duquesne, Pa.	Nov. 20, 1895
FRY, DONALD HUME	The Standard Electric Co., Jackson, Amador Co., Cal.	Nov. 23, 1898
FULLER, EDWIN ERNEST	Representative Engineer for Scotland for The British Thomson-Houston Co.; residence, Abbottsford, St. Andrews St. Ayr N. B. England.	Feb. 28, 1902
GALLAHER, EDWARD B.	The Keystone Motor Co., Drexel Building; residence, 1230 Orkney St., Philadelphia, Pa.	Jan. 19, 1895
GALLATIN, ALBERT R.	Student at Columbia University, residence 58 W. 55th St., New York City.	Mar. 23, 1898
GANZ, ALBERT F.	Assistant Professor, Physics and Applied Electricity. Stevens Institute; residence 612 River St., Hoboken, N. J.	April 26, 1899
GARRELS, W. L.	Consulting Engineer, Franklin Bank B'ld'g.; residence, 4531 West Pine Boulevard, St. Louis, Mo.	Mar. 20, 1895

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Name.	Address.	Date of Election.
GARTLEY, ALONZO	General Manager, Hawaiian Electric Co., Honolulu, H. I.	July 12, 1900
GAYLORD, TRUMAN PENFIELD	Manager, Chicago Office, Westinghouse E. & Mfg. Co., 171 La Salle St.; residence, 610 Dearborn Ave., Chicago, Ill.	Feb. 28, 1902
GAYTES, HERBERT	Electrical Engineer, Oakland, Cal.	Mar. 23, 1898
GEAR, HARRY BARNES	General Inspector, Chicago Edison Co., 139 Adams St., Chicago, Ill	Oct. 25, 1901
GEORGE, JAMES ZACKARIAH	General Manager and Chief Engineer, Street Railway and Lighting Plant, Vicksburg, Miss.	Sept. 27, 1901
GHERARDI, BANCROFT, JR.,	Chief Engineer, New York and New Jersey Telephone Co., 81 Willoughby St., Brooklyn; residence, 360 W. 21st St., New York City.	June 27, 1895
GIBBONEY, WILLIAM KENT	Assistant to the Superintendent, The Niagara Falls Power Co.; residence, 539 Fourth St., Niagara Falls, N.Y.	Sept. 27, 1901
GIBSON, GEO. H.	Westinghouse Co.'s Publishing Dept.; Office, East Pittsburg; residence, 268 Shady Ave., Pittsburg (East End), Pa.	Nov. 22, 1899
GIBSON, JOHN JAMESON	Salesman Westinghouse E. & Mfg. Co., 171 La Salle St, Chicago, Ill	Feb. 28, 1902
GILLE, HENRY JOHN	Supt. Electric Dept., St. Paul Gas Light Co., St. Paul, Minn.	Jan. 25, 1901
GILLILAND, E. T.	Pelham Manor, N. Y.	April 15, 1884
GILLIS, HARRY ALEXANDER	General Superintendent, Richmond Locomotive Works, Richmond, Va.	Apr. 26, 1901
GILMAN, FRANCIS LYMAN	Telephone Engineer, Western Electric Co., 463 West St., New York City; residence, 49 Christopher St., Montclair, N. J.	June 28, 1901
GLASS, LOUIS	Assistant General Manager, Pacific Telegraph and Telephone Co., Telephone Bldg.; residence, 216 Bush St., San Francisco, Cal.	Oct. 24, 1900
GOLDMARK, CHAS. J.	Consulting Electrical Engineer, 66 New Street, Tel. 2729 Broad, New York City.	June 5, 1888
GORDON, REGINALD	Residence, 315 W. 71st St., New York City.	Feb. 24, 1891
GORRISSEN, CH.	Siemens Bros. & Co., Ltd., York Mansions, York St., Westminster, London S. W.	Mar. 25, 1896
GORTON, CHARLES	Civil Engineer, Belmont, N. Y.	Nov. 12, 1889
GOUGH, HARRY EUGENE	Assistant in Office Mechanical Engineers, Penn R. R. Co., 1415 11th St., Altoona, Pa.	Jan. 9, 1901
GRAHAM, WILLIAM P.	Professor of Electrical Engineering, Syracuse University, 504 University Place, Syracuse, N. Y.	Jan. 24, 1902

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Name.	Address.	Date of Election.
GRANBERY, JULIAN H.	Residence, 561 Walnut St., Elizabeth, N. J.	Aug. 5, 1896
GRANT, LOUIS T.	General Delivery, Manila, P. I.	Nov. 22, 1899
GRANT, OLIVER REMICK	Student, Columbia University; residence, 2236 Southern Boulevard, Bronx Borough, New York City.	Mar. 28, 1902
GRAVES, CHAS. B.	Halifax Electric Tramway Co., Halifax, N. S.	Sept. 15, 1897
GRAY, CLYDE D.	Assistant in Electrical Department, J. G. White & Co., 29 Broadway, New York City; residence 50 Pierrepont St., Brooklyn, N. Y.	Apr. 25, 1902
GRAY, EDWARD WYLLYS TAYLOR.	Manager, New York Sales Office, Westinghouse Elec. & Mfg Co., 120 Broadway, New York City; residence, Montclair, N. J.	Jan. 3, 1902
GREEN, ELWYN CLINTON	With Commercial Electric Co.: residence, 1710 Prospect St., Indianapolis, Ind.	Mar. 25, 1896
GREENLEAF, LEWIS STONE	General Superintendent, Hudson River Telephone Co., Albany, N. Y.	Aug. 5, 1896
GREENWOOD, FRED. A.	Secretary California Electric Works, 409 Market St., San Francisco, Cal.	April 28, 1897
GREENWOOD, GEORGE	Electrical Engineer and Superintendent, Jalapa Railway and Power Co., Jalapa, V. C., Mexico.	Jan. 24, 1900
GRIFFEN, JOHN D.	Inventor, Electric Conduit and Electric Signaling Apparatus, Broad-Exchange B'ld'g, 25 Broad St.; residence, 304 West 90th St., New York.	Aug. 13. 1897
GRIFFES, EUGENE V.	c/o United Electric Co., Long Beach, Cal.	Feb. 26, 1896
GRIFFIN, GEN. EUGENE	First Vice-President, General Electric Co., 44 Broad St., New York City.	Feb. 7, 1890
GRISSINGER, ELWOOD	Engineer, The Cataract Power & Conduit Co., 40 Court St., Buffalo, N. Y.	Mar. 28, 1902
GROWER, GEORGE G.	Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn.	Mar. 18, 1890
GUERRERO, JULIO	Associated with the Durango Electric Light Co., Victoria, 12 Durango, Mex.	April 25, 1900
GUTIERIEZ, MANUEL R.	Professor of Physics, Normal School, Jalapa, V. C., Mexico.	April 25, 1900
GUY, GEORGE HELI	Secretary, The New York Electrical Society, 114 Liberty St., New York City.	May 16, 1893
HAKONSON, CARL HAROLD	Electrical Engineer, Södertelge, Sweden.	Sept. 25, 1895
HALL, CLARENCE MORTIMER	Teacher of Physics and Electricity, Manual Training School No. 1, 7th St. and R. I. Ave., N. W.; residence, 605 Florida Ave., N. W., Washington, D. C.	Mar. 28, 1902

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Name.	Address.	Date of Election.
HALL, EDWARD J.	Vice-President and General Manager, American Telephone and Telegraph Co., 15 Dey St., New York City.	April 18, 1893
HALL, FRED'K A.	Engineer, The Johnson-Lundell Electric Traction Co., Ltd., 16 Soho Square, London, W.	Aug. 23, 1899
HALL, HARRIOTT CURTIS	Student, Polytechnic Institute, Brooklyn, N. Y.; residence, Glen Cove, L. I.	June 28, 1901
HALLBERG, J. HENRY	Electrician, General Incandescent Arc Light Co., 572 First Ave.; residence, 3 Beech Terrace, E. 143d St., New York City.	Aug. 23, 1899
HAMERSCHLAG, ARTHUR A.	Consulting Engineer, 41 Liberty St., New York City.	Mar. 25, 1896
HAMILTON, JAMES	Patent Law Specialist. 53 State St., Boston, residence, 205 Crafts St., Newtonville, Mass.	Nov. 23, 1898
HAMILTON, RALPH BERGEN	Manager, The Packard Electric Co., Ltd., St. Catharines, Ont.	Nov. 22, 1901
HAMMATT, CLARENCE S.	Manager, Jacksonville Electric Light Co., Jacksonville, Fla.	Sept. 20, 1893
HANCOCK, L. M.	Supt., Nevada Division, Bay Counties Power Co., P. O. Box 151, Nevada City, Cal.	May 19, 1891
HANSCOM, WM. W.	Chief Electrical Engineer, Union Iron Works, 612 O'Farrell Street, San Francisco, Cala.	April 25, 1900
HANKS, MARSHALL WILFRED	Engineer, Nernst Lamp Co.; residence, Amber Club, Pittsburg, Pa.	Jan. 3. 1902
HANSON, ARTHUR JAMES	Lawrence & Hanson, 3 Wynyard St., residence, Drunnmoyne, Sydney, N. S. W.	Nov. 22, 1899
HARDING, H. McL.	20 Broad Street, New York City.	May 24, 1887
HARDY, CARL EARNEST	Master Electrician, U. S. Navy Yard, Norfolk, Va.; residence, 206 London St., Portsmouth, Va.	Dec. 27, 1899
HARRIS, GEORGE H.	Chief Engineer, Birmingham Railway Light and Power Co., Birmingham, Ala.	June 20, 1894
HARRIS, GRENVILLE A.	Electrical and Mechanical Engineer, Takata & Co., 10 Wall St., New York City; residence, Elizabeth, N. J.	Oct. 25, 1901
HARTER, BRET	With E. P. Roberts & Co., Cleveland, Ohio.	July 26, 1900
HARTMAN, HERBERT T.	2nd Vice-President and Chief Engineer, 1406 Land Title B'ld'g., residence, 3135 Clifford St., Philadelphia, Pa.	Mar. 21, 1893
HARVEY, ROBERT R. [Life Member.]	10 So. Franklin St., Wilkes-Barre, Pa.	Sept. 25, 1895

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Name.	Address.	Date of Election.
HASKINS, WILLIAM EDGAR	Chief Electrician, South Works, American Steel and Wire Co., 209 Vernon St., Worcester, Mass.	Jan. 25, 1901
HASSLER, CHAS. T. F.	Electrical Engineer, "Union" Co., Riga, Russia.	Oct. 24, 1900
HATHAWAY, JOSEPH D., JR.	Superintendent, The Wire & Cable Co., Montreal, Quebec.	Aug. 5, 1896
HATZEL, J. C.	Firm Hatzel and Buehler, 114 Fifth Ave., residence, 1231 Madison Ave., New York City.	Sept. 3, 1889
HAUBRICH, ALEX. MICHAEL	Electrical Engineer, with Strom-berg-Carlson Telephone Mfg. Co., 72 West Jackson Boulevard, Chicago, Ill.	April 26, 1901
HAWKS, H. D.	Engineer, with General Electric Co., Schenectady, N. Y.	May 21, 1901
HEALY, LOUIS W.	Treasurer, East Liverpool Railway Co., East Liverpool, Ohio.	June 26, 1891
HEANY, JOHN ALLEN	Expert. Teter-Heany Developing Co., 904 Quarry St., Philadelphia, Pa.	Oct. 25, 1901
HEDENBERG, WM. L.	Manager and Editor, *Electricity*, 136 Liberty Street, New York City.	Nov. 21, 1894
HEFT, N. H.	Chief of Electrical Dep't N.Y.N.H. & H. R. R., New Haven; residence, Bridgeport, Conn.	Aug. 23, 1899
HEITMANN, EDWARD, JR.,	Stanley Electric M'fg. Co., Pittsfield, Mass.	Oct. 24, 1900
HELLICK, CHAUNCEY GRAHAM	Chicago Telephone Co., 203 Washington St , Chicago, Ill.	Jan. 26, 1898
HEMINGWAY, ALBERT FRANKLIN	Chief Draughtsman, The Western Electric Co., 463 West St ; residence, 143 W. 122d St., New York City.	Sept. 27, 1901
HENDERSON, ALEX.	Electrician, Sprague Electric Co., residence, 146 W. 104th St. N. Y.	Nov. 30, 1897
HENDERSON, HENRY BANKS	Riverside, Cal.	May 21, 1895
HENRY, GEORGE CLINTON	Sales Manager. Florida Electric Co., 33 W. Forsythe St., Jacksonville, Fla.	Jan. 3, 1902
HENRY, GEO. J., JR.,	Engineer for The Pelton Water Wheel Co., 143 Liberty St , New York and 127 Main St., San Francisco, Cal.	April 27, 1898
HENRY, IRA WALTON	Cable Engineer, The Safety Cable Co., 229 W. 28th St., New York City.	May 21, 1901
HENRY, LEWIS WARNER	Assistant in Engineering Department, Mexican General Electric Co , Mexico City.	Feb. 28, 1900
HERDT, LOUIS A.	Lecturer on Electrical Engineering, McGill University, Montreal, Canada.	May 16, 1899
HERMESSEN, JOHN LOUIS	83 Cannon St., London, E. C., England.	Jan. 20, 1897

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Name.	Address.	Date of Election.
HERRICK, ALBERT B.	Consulting Electrical Engineer, 120 Liberty St., New York City; residence, Ridgewood, N. J.	May 21, 1901
HERZOG, JOSEF	Chief of Installations Department, Ganz & Co. V. Elisabetplatz 1, Budapest, Hungary.	Jan. 3, 1902
HESKETH, JOHN	Electrical Engineer, Queensland Government Post and Telegraph Dept., Brisbane, Queensland.	May 21, 1901
HESSENBRUCH, GEORGE S.	*E.E. Ph.D.* Ass't Engineer to Sup't of Structure, 205 Union Station, Terminal R. R., residence, 514 N. Spring Ave., St. Louis, Mo.	June 27, 1895
HEWITT, CHARLES E.	Electrician, Hyer-Sheehan Electric Motor Co., 139 Chamber St., Newburgh, N. Y.	Sept. 25, 1895
HEWITT, PETER COOPER	11 Lexington Ave., New York City.	May 21, 1901
HEWITT, WILLIAM R.	Chief, Department of Electricity, 9 Brenham Place, San Francisco, Cal.	May 15, 1894
HEWLETT, EDWARD M.	Engineer, General Electric Co., residence, 27 University Place, Schenectady, N. Y.	May 19, 1891
HILDBURGH, WALTER LEO	Student, Columbia University; c/o D. H. Hildburgh, Hotel Normandie, New York.	Dec. 28, 1898
HILL, ERNEST ROWLAND	Electrical Engineer, The British Westinghouse E. & M. Co., Ltd., Westinghouse Building, Norfolk St., Strand, London W. C., Eng.	Jan. 25, 1899
HILL, G. HENRY	Engineer, Sprague Electric Co., 527 W. 34th St., New York City; residence, 11 Hamilton Road, Glen Ridge, N J.	Jan. 25, 1899
HILL, NICHOLAS S., JR.	Consulting Engineer, 520 Equitable Bldg., Baltimore, Md., and 100 William St., New York City.	Aug. 5, 1896
HILLMAN, H. W.	General Electric Co, Schenectady, N. Y.	Jan. 3, 1902
HINES, CHARLES HENRY	Superintendent Electrical Department, Lorain Steel Co., 544 14th Ave., Lorain, Ohio.	Apr. 25, 1902
HITZEROTH, L. D.	President, Century Electric Co., 18 Second St., San Francisco, Cal.	July 26, 1900
HOAG, GEO. M.	City Electrician, City of Cleveland, 113 City Hall; residence, 317 Hough Ave., Cleveland, O.	April 28, 1897
HODGE, CHARLES	Salesman, Westinghouse E. & M. Co., 120 Broadway, residence, 201 W. 78th St., New York City.	Mar. 28, 1902
HODGE, WILLIAM B.	Electrical Engineer, Queen & Co., 1010 Chestnut St., Philadelphia, Pa.	Dec. 28, 1898

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Name.	Address.	Date of Election.
HODGES, WILLIAM LEMMON	Engineer of Equipment, Keystone Telephone Co., Keystone Telephone Building, Second and Sansom Sts.; residence, 3153 Woodland Avenue, Philadelphia, Pa.	April 26, 1901
HOFFMANN, BERNHARD	New York Telephone Co., 113 W. 38th St., residence, 12 W. 18th St., New York City.	Nov. 23, 1898
HOGAN, CHARLES WILLIAM	Assistant Superintendent, The Capital Electric Co., Denver, Col.	Mar. 28, 1902
HOLBERTON, GEORGE C.	General Supt. Electric Department, Oakland Gas Light and Heat Co., 13th & Clay Sts., Oakland, Cal.	May 15, 1894
HOLBROOK, FREDERICK MONTGOMERY	Electrical Engineer, Crocker-Wheeler Co., Old Colony Building, Chicago, Ill.	Sept. 27, 1901
HOLBROW, HERMAN L.	Draughtsman, Equipment Dept., Navy Yard; residence, 112 Waverly Ave., Brooklyn, N. Y.	Mar. 24, 1897
HOLMES, GWYLLYN R.	Holmes-Rose Electric Co., No. 215 Calvert St., residence 2842 Parkwood Ave., Baltimore, Md.	Jan. 24, 1900
HOLT, MARMADUKE BURRELL,	Mining and Electrical Engineer, Silverton, Col.	April 15, 1890
HOLTZER, CHAS. WM. [Life Member.]	President Holtzer-Cabot Electric Co., Brookline, Mass.	May 21, 1901
HOMMEL, LUDWIG	Supt. of Construction, Standard Underground Cable Co., 618 Westinghouse Bldg, Pittsburg, Pa.	Jan. 20, 1897
HOOD, RALPH O.	Electrical Engineer, Danvers, Mass.	April 18, 1894
HOOPES, MAURICE	Mechanical Engineer, J. G. White Co., 29 Broadway; residence, 1 West 89th St., New York City.	Nov. 22, 1901
HOPEWELL, CHAS. F.	Inspector of Wires, Supt. of Lamps, Fire Alarm and Police Telegraph, City of Cambridge, City Hall; residence, 82 Magazine St., Cambridgeport, Mass.	Aug. 13, 1897
HOPKINS, NEVIL MONROE, *M.S.*	Electro-Chemist and Electro-Chemical Engineer, Instructor in Chemistry and Electro Chemistry in the Columbian University, 1730 I Street, N. W., Washington, D. C.	Nov. 20, 1895
HOPKINS, N. S.	Designing Engineer, General Electric Co., Lynn, Mass.	April 27, 1898
HOPTON, WALTER EDWIN	General Supt., Cincinnati Edison Electric Co., Cincinnati, O.	April 26, 1901
HORN, HAROLD J.	Electrical Engineer, John A. Roebling's Sons' Co.; residence, 36 W. State St., Trenton, N. J.	Mar. 22, 1899
HOWE, WINTHROP KEITH	Assistant Engineer, Taylor Signal Co., Carroll and Wells Sts., Buffalo, N. Y.	Mar. 22, 1901

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Name.	Address.	Date of Election.
HOWES, ROBERT	Asst. Supt. of the Light and Power System of Washington Water Power Co., Box 1587, Spokane, Wash.	Jan. 25, 1901
HOWSON, HUBERT	Patent Lawyer, 38 Park Row, New York City.	June 8, 1887
HOXIE, GEORGE L.	Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City.	Feb. 28, 1901
HUBBARD, ALBERT S.	Gould Storage Battery Co., Astor Court B'ld'g, 25 W. 33rd St.; residence, Greenwich, Conn.	Nov. 20, 1895
HUBBARD, WILLIAM C.	Vice-President, Electric Arc Light Co., Sales Manager Manhattan General Construction Co., 120 Broadway, New York, residence, 427 West 7th St., Plainfield, N. J.	April 18, 1894
HUBRECHT, DR. H. F. R.	Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland.	Oct. 4, 1887
HUGGINS, N. W.	Salesman, etc., General Electric Co., Seattle, Wash.	Aug. 5, 1896
HUGUET, CHAS. K.	Electrical Engineer, 753 Jackson Boulevard, Chicago, Ill.,	June 27, 1895
HULSE, WM. S.	Electrical Engineer, with Union Elektricitäts Gesellschaft, Doratheen Str. 43, Berlin, Germany.	Mar. 25, 1896
HUMPHREYS, C. J. R.	Manager, Lawrence Gas Co., and Edison Electrical Ill Co., Lawrence, Mass.	Sept. 6, 1887
HUNT, ARTHUR L.	Harrisburg Foundry and Machine Works, 203 Broadway, New York City.	Sept. 19, 1894
HUNT, A. M.	Consulting Engineer, 331 Pine Street, San Francisco, Cala.	Feb. 28, 1900
HUNT, CHARLES WALLACE	President, C. W. Hunt Co., Stapleton, N. Y.	Apr. 25, 1902
HUNTLEY, CHAS. R.	General Manager, Buffalo General Electric Co., 40 Court St., Buffalo, N. Y.	Sept. 25, 1895
HUTTON, CHAS. WILLIAM	Chief Electrician, Sacramento Electric Gas and Railway Co., Sacramento, Cal.	Feb. 15, 1899
HUTCHINSON, FREDERICK L.	Advertising Manager, Christensen Engineering Company, Milwaukee, Wis.	June 20, 1894
HUTCHINSON, ROLIN WILLIAM, JR.	Student, Polytechnic Institute; residence, 302 Clinton Street, Brooklyn, N. Y.	Jan. 3, 1902
HYDE, J. E. HINDON	Patent Lawyer, 120 Broadway, New York City.	Jan. 24, 1900
IDELL, FRANK E.	Havemeyer Building, 26 Cortlandt St., New York City.	July 12, 1887
IHLDER, JOHN D.	Electrical Engineer, Otis Elevator Co., Yonkers, N. Y.	Oct. 2, 1888

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Name.	Address	Date of Election.
IIJIMA ZENTARO,	Electrical Engineer, Shibaura Engineering Works, 1 Shinhamacho, Shiba, Tokyo, Japan.	Jan. 22, 1896
IMLAY, L. E.	Resident Engineer, Westinghouse Elec & M'fg. Co., 37 McGill College Ave., Montreal, Quebec.	July 26, 1900
INSULL, MARTIN J.	2d Vice-President and General Manager, General Incandescent Arc Light Co., 572 First Ave.; residence, 262 W. 83d St., New York City.	Nov. 22, 1899
INSULL, SAMUEL	President, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Dec. 7, 1886
IWADARE, KUNIHIKO	Electrician, Nippon Electric Company, 2 Mita Shikokumachi Shibaku, Tokyo, Japan.	Sept. 20, 1893
JACKSON, E. D.	82 Beech St., Detroit, Mich.	Nov. 22, 1899
JACKSON, WM. STEELL	4th Assistant Examiner, Patent Office; residence, 325 Spruce St., N. W., Washington, D. C.	April 22, 1896
JAEGER, CHARLES L.	Inventor, Maywood, N. J., Electric Recording Ship Apparatus, Laboratory, 132 Mulberry St., New York, N. Y.	Dec. 20, 1893
JAMES, HENRY DUVALL, *B.S.*, *M.E.*	Engineering Department, The Hollar Lock Inspection and Guaranty Co., 421 Chestnut St.; residence, 255 South Eighth St., Philadelphia, Pa.	Nov. 23, 1898
JANISCH, CHARLES	Chief Engineer, The Siemens & Halske Co.; Siegmunds No. 12, Berlin, Germany.	Oct. 25, 1901
JAQUAYS, HOMER M.	Lecturer in Mechanical Engineering, McGill University, residence, 862 Sherbrooke St., Montreal, Quebec.	Dec. 27, 1899
JENKS, ARTHUR PERKINS	Railway Department, General Elecrric Co., Schenectady, N. Y.	May 21, 1901
JOHNSON, ALBERT C.	Superintendent and Electrician, Electric Light & Water Works, Box 308, Willmar, Minn.	May 16, 1899
JOHNSON, CHARLES E.	Mexico City Tramway Co., Mexico City, Mexico.	May 15, 1900
JOHNSON, HOWARD S.	Jeffrey M'f'g Co., 303 Kanawha St., Charleston, W. Va.	Mar. 22, 1899
JOHNSON, WALLACE CLYDE	Consulting Engineer, Water Power and Transmission, Niagara Falls, N. Y.	Mar. 22, 1901
JOHNSON, WARREN S.	Johnson Electric Service Co., 120 Sycamore St., Milwaukee, Wis.	Sept. 27, 1901
JOHNSON, WOOLSEY MCALPINE	Electro-Metallurgist, Orford Copper Co., New Brighton, S. I., N. Y.	Mar. 28, 1902
JOHNSTON, THOS. J.	Counsel in Patent Causes, 66 Broadway, New York City.	May 16, 1899

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Name.	Address.	Date of Election.
JOHNSTON, W. J.	President, *The Engineering and Mining Journal*, 261 Broadway, New York City.	April 15, 1884
JONES, ARTHUR W.	Managing Director, Australian General Electric Co., Equitable Bldg., Melbourne, Australia.	Oct. 17, 1894
JONES, FORREST R.	Professor of Drawing and Machine Design, Worcester Polytechnic Institute, residence, 3 State St., Worcester, Mass.	May 20, 1890
JONES, FRED ATWOOD	Consulting Electrical, Mechanical and Hydraulic Engineer, Room 204 Kiam Building, Houston, Texas.	Jan. 24, 1902
JONES, G. H.	Agent, General Electric Co., Casilla 1317 Santiago, Chile.	April 17, 1895
JONES, HENRY C.	Member of Firm, the Electric Construction and Supply Co., Montgomery, Ala.	Mar. 20, 1895
JONES, M. E.	Chief Engineer, St. Lawrence State Hospital, Ogdensburg, N. Y.	Oct. 27, 1897
JOSLYN, HOWARD.	Assistant Engineer, Snoqualmie Falls Power Co., 507 Pioneer Bldg, Seattle, Wash.	May 17, 1898
JUDSON, HANFORD CHASE	Assistant Engineer, General Electric Co., Dobbs Ferry, N. Y.	Apr. 25, 1902
JUDSON, WM. PIERSON	Deputy State Engineer, of New York, Albany; residence, Oswego, N. Y.	June 8, 1887
JUNKERSFELD, PETER	Assistant to Mechanical Engineer, Chicago Edison Co., 139 Adams St; residenoe, 114 South Austin Boulevard, Austin, Chicago, Ill.	Oct. 25, 1901
KAMMERER, JACOB A.	General Agent, The Royal Electric Co.; residence, 87 Jameson Ave., Toronto, Ont.	April 28, 1897
KEBLER, JOHN LEONARD	Vice-President Ward-Leonard Electric Co., Lawrence Park, Bronxville, N Y.	May 21, 1901
KEEFER, EDWIN S.	Supt. of Electric Light Construction, Western Electric Co., 463 West St., New York City; residence, Elizabeth, N. J.	April 18, 1894
KEILHOLTZ, P. O.	General Manager, United Electric Light and Power Co., and Chief Engineer, United Railways and Electric Co., Continental Trust Building, Baltimore, Md.	Mar. 21, 1893
KELLER, CARL A.	With J. G. White & Co., Little Rock, Ark.	Sept. 27, 1901
KELLER, E. E.	Vice-President and General Manager, Westinghouse Machine Co, Pittsburg, Pa.;	Sept. 20, 1893

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Name.	Address.	Date o Election
KELLOGG, JAMES W., *M.E.*	Manager Marine Sales, General Electric Co.; residence, 10 Front St., Schenectady, N. Y.	June 26, 1891
KELLY, JOHN F.	The Stanley Electric Co.; residence, 284 West Housatonic St., Pittsfield, Mass.	May 16, 1899
KELSEY, JAMES CEZANNE	Purdue University, Lafayette. Ind.	Nov. 23, 1900
KENNEDY, A. P. [Life Member.]	Electrical Engineer, Central District, American Can Co., Maywood, Ill.	Apr. 26, 1899
KENNEDY, JEREMIAH J.	Consulting Engineer, 52 Broadway, New York.	July 26, 1900
KENT, JAMES MARTIN	Instructor in Steam and Electricity, Manual Training High School, Kansas City, Mo.	July 26, 1900
KER, W. WALLACE	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant St., New York City. Residence, 626 Pavonia Ave., Jersey City, N. J.	Sept. 25, 1895
KERR, SAMUEL ROSS	Testing Department, Bullock Electric Mfg. Co.; residence, Cor. Norwood Ave. & Marion St., Norwood, Ohio.	Jan. 3, 1902
KERSHNER, JEFFERSON E	Consulting Engineer, The Lancaster County R. & L. Co., 445 W. Walnut St., Lancaster, Pa.	Jan. 3, 1902
KIER, SAMUEL MARTIN	Electrical Engineering Dept., Westinghouse E. & M. Co.; residence, 5904 Elgin Ave., Pittsburg, Pa.	Jan. 24, 1902
KING, HARRY R.	Electrical Engineer, Western Electric Co., 259 S. Clinton St., Chicago, Ill.	Nov. 22, 1901
KING, VINCENT C., Jr.	With V. C. & C. V. King, 517 West St.; residence, 110 East 16th Street, New York.	Aug. 5, 1896
KINSLEY, CARL	Quadrangle Club, Chicago, Ill.	May 18, 1897
KINTNER, CHARLES JACOB	Solicitor of Patents and Expert, 45 Broadway; residence, 36 E. 29th St., New York City.	Feb. 28, 1902
KINTNER, SAMUEL MONTGOMERY	Professor of Electrical Engineering, Western University of Pa.; residence, 1916 Perrysville Ave., Allegheny, Pa.	Feb. 28, 1902
KITTLER, DR. ERASMUS	Professor at the Technical High School, Darmstadt, Germany.	Dec. 16, 1896
KLAUDER, RUDOLPH H.	Electrical Engineer, 817 Wainwright Bldg, St. Louis, Mo.	Aug. 13, 1897
KLINCK, J. HENRY	Klinck and Kodjbanoff, 5 So. 9th St Reading, Pa.	Jan. 16, 1895
KLINE, JAMES JOSEPH	Engineering Student, Stanley Electric Mfg. Co ; residence, Beech Grove Inn, Pittsfield, Mass.	Jan. 3, 1902
KNIGHT, PERCY HENRY	District Engineer, Westinghouse E. and M. Co., San Francisco, Cal.	Mar. 28, 1902
KNOX, FRANK H.	Engineer, Spartanburg Railway, Gas & Electric Co., Spartanburg S. C.	June 20, 1894

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Name.	Address.	Date of Election.
KNOX, GEO. W.	2329 Magnolia Ave., Chicago, Ill.	Nov. 18, 1896
KNOX, S. L. G.	Manager and Chief Engineer, Bucyrus Co., South Milwaukee, Wis.	Nov. 23, 1898
KREIDLER, W. A.	Editor and Publisher, *Western Electrician*, 510 Marquette Building, Chicago, Ill.	Oct. 4, 1887
KRUESI, AUGUST H.	Designing Engineer, General Electric Co.; residence, 16 Union Street, Schenectady, N. Y.	Jan. 9, 1901
KRUESI, PAUL JOHN	Manager, Sunlight Lava Mfg. Co., 31 Market Square; residence, 12 B St., Chattanooga, Tenn.	Oct. 25, 1901
LAFORE, JOHN ARMAND	Electrical Engineer, Overbrook, Pa.	May 15, 1900
LAMB, FRANCIS JOSEPH	Electrical Engineer, Lamb & Co., cor. Kent and Lyon Sts., Grand Rapids, Mich.	Jan. 3, 1902
LAMB, RICHARD	Chief Engineer, Brooklyn Dock and Terminal Co., and the Brigantine Trolley Co., 136 Liberty St.; residence, Waterwitch Park, Highlands, N. J.	Dec. 18, 1895
LAND, FRANK, *M. E.*	Sec'y and Treas., I. A. Weston Co., residence, 102 Highland Ave., Syracuse, N. Y.	Sept. 22, 1891
LANMAN, WILLIAM H.	Board of Patent Control, 120 Broadway, New York City.	June 6, 1893
LANPHEAR, BURTON S.	Assistant Professor of Electrical Engineering, Iowa State College, Ames, Iowa.	Jan. 16, 1895
LANPHIER, ROBERT CARR,	Superintendent and Electrician, Sangamo Electric Co., Springfield, Ill.	Nov. 22, 1901
LANSINGH, VAN RENSSELAER	Electrical and Illuminating Engineer, 18 E. Adams St.; residence, 5329 Kimbark Ave., Chicago, Ill.	Aug. 23, 1899
LATHAM HARRY MILTON	With American Steel and Wire Co., Worcester, Mass.	Dec. 16, 1896
LAWRENCE, WM. G.	Manager of Light and Power Department, Town of Hudson, Hudson, Mass.	Feb. 28, 1900
LAWRENCE, W. H.	Assistant Superintendent, Second District, The New York Edison Co., 49 West 26th St., New York, N. Y.	April 26, 1899
LAYTON, GORDON	Electrical Engineer, British Westinghouse E. & M. Co.; residence, 48 Lancaster Park, Richmond, England.	Jan. 3, 1902
LEBLANC, CHARLES	Engineer, 7 Rue Meyerbeer, Paris, France.	April 17, 1895
LEBLANC, MAURICE	Consulting Electrical Engineer, Westinghouse Electric and M'f'g Co.; residence, Villa Montmorency, Paris, France.	Apr. 25, 1902

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Name.	Address.	Date of Election.
LECLEAR, GIFFORD,	Electrical and Mechanical Engineer, Partner Densmore & Le Clear, 15 Exchange Street, Boston, Mass.; residence, Cambridge, Mass.	Oct. 27, 1897
LECONTE, JOSEPH NISBET	Instructor in Electrical Engineering, State University, Berkeley, Cal.	Feb. 27, 1895
LEDOUX, A.R., *M. S., Ph.D.*,	President of Ledoux & Co.(inc.), 99 John St., residence, 39 W. 50th St., New York City.	Dec. 7, 1886
LEE, FRANCIS VALENTINE T.	Engineer, (Pacific Coast Dept.) Stanley Electric M'f'g. Co., 33 New Montgomery St., San Francisco, Cal.	Mar. 23, 1898
LEE, JOHN C.	Chemist and Electrician, American Telephone & Telegraph Co., Boston, residence, Mountfort St., Longwood, Brookline, Mass.	Mar. 18, 1890
LEEDS, NORMAN	Electrical Engineer, National Cash Register Co., Dayton, Ohio.	Feb. 28, 1901
LEEDS, MORRIS EVANS	Managing Member of the firm, Morris E. Leeds & Co., 259 North Broad St.; residence, 3221 N. 17th St., Philadelphia, Pa.	Apr. 26, 1901
LEITCH, HOWARD WALLACE	Switchboard Regulator. The Edison Elect. Illuminating Co., residence, 373 Madison St., Brooklyn, N. Y.	Nov. 23, 1898
LETHEULE, PAUL	Electrical Engineer, Commissioned by French Government, 52 Rue de Clichy, Paris, France.	May 17, 1898
LEWIS, HENRY FREDERICK WILLIAM,	25 College Hill, Cannon St., London, England.	Mar. 5, 1889
LIBBY, SAMUEL BYINGTON	Richmond Borough Equipment Co., 395 Richmond Terrace, New Brighton, N. Y.	Feb. 23, 1898
LILLEY, L. G.	Electrician, The Cincinnati Underwriters' Association S. W. Cor. 3d and Walnut Sts., Cincinnati, O.; residence, Wyoming, O.	June 20, 1894
LILLIBRIDGE, RAY D.	20 Broad St., New York City.	Jan. 24, 1902
LINDSAY, ROBERT	General Supt. The Cleveland Elec. Ill. Co., 717 Cuyahoga Building, Cleveland, Ohio.	April 27, 1898
LISLE, ARTHUR BEAMER	General Representative, Narragansett Electric Lighting Co., Box 1223, Providence, R. I.; residence, East Greenwich, R. I.	Jan. 9, 1901
LITTLE, C. W. G.	Engineering Manager, The British Electric Traction Co., Ltd., Donington House, Norfolk St., Strand, W. C., London; residence, 4 Mount Adon Park, Dulwich, S. E., Eng.	April 22, 1896

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Name.	Address.	Date of Election.
LIVINGSTON, JOHNSTON JR.	The United Engineering and Contracting Co., 13 Park Row, New York City.	May 17, 1898
LIVSEY, J. H.	Salesman and Manager Detroit Office General Electric Co., 704 Chamber of Commerce, Detroit, Mich.	April 25, 1900
LLOYD, EDWARD WILLIAM	Assistant Superintendent of Construction, Chicago Edison Co., 139 Adams St., Chicago.	Feb. 28. 1902
LOBO, GUSTAVE	Office Engineer, V. M. Braschi & Bro., Apartado No. 830, and Calle-Cadera No. 2, Mexico City, Mexico.	June 28, 1901
LOEWENTHAL, MAX	Supt. Max Osterberg, 11 Broadway; residence, 100 St. Nicholas Ave., New York City.	Mar. 23, 1898
LOHMANN, R. W.	With Bion J. Arnold, 711 Transit Building, New York City.	Nov. 23, 1898
LORIMER, GEO. WM.	Sec'y and Treasurer, The American Machine Telephone Co., Ltd., Piqua, O.	Aug. 5, 1896
LOUIS, OTTO T.	Manager of New York Branch, Queen & Co., Inc.; residence, 340 East 119th St., New York City.	Feb. 23, 1898
LOVEJOY, D. R.	Electrical Engineer, c/o Cataract Chemical Co., Niagara Falls, N. Y.	April 28, 1897
LOW, GEORGE P.	Editor and Proprietor, *Journal of Electricity, Power and Gas*, 320 California St., San Francisco, Cal.	Jan. 17, 1893
LOWSON, DAVID	Electrical Inspector, Department of Electricity, 1721 Park Row Building; residence, 35 W. 132d St., New York City.	Feb. 28, 1902
LOWTHER, CHRISTOPHER MEYER,	Sales Engineer Crocker-Wheeler Co., New York; residence, 168 Arlington Ave., East Orange, N. J.	Nov. 23, 1900
LUDVIGSEN, HANS VALDEMAR	Electro-Chemical Engineer, Blaagaardsgade 17, Copenhagen; residence, Straudvejen 116, Hellerup, Denmark.	Nov. 22, 1901
LUKES, GEORGE HOLT	Night Operating Superintendent, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Oct. 25, 1901
LUNDELL, ROBERT	Electrical Engineer, 527 W. 34th St., residence, 9 W. 68th St., New York City.	Feb. 7, 1890
LUNDIE, JOHN	Consulting Engineer, 52 Broadway, New York City.	Nov. 22, 1899
LYFORD, OLIVER S., JR.,	Electric Boat Co., 100 Broadway, New York, N. Y.	Apr. 26, 1899
LYMAN, CHESTER WOLCOTT, *M. A.*	Assistant to President International Paper Co., 30 Broad St., residence, University Club, New York, N. Y.	Sept. 19, 1894

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Name.	Address.	Date of Election.
LYNDON, LAMAR	Consulting Electrical Engineer, Park Row Building (Telephone, 1650 Cortlandt); residence, 243 W. 98th St., New York City.	Sept. 27, 1901
LYNN, WM. A.	Instructor in Electrical Engineering, University of California, Berkeley, Cal.	Jan. 25, 1899
LYONS, JOSEPH,	Patent Solicitor, with Gustav Bissing 908 G. St., Washington, D. C.	June 24, 1898
MACARTNEY, JOHN F.	Managing Director, Macartney, McElroy & Co., L't'd., 53 Victoria St., London, Eng.	May 16, 1899
MACCALLA, CLIFFORD SHERRON	Assistant Electrical Engineer, N. S. W. Government Tramways Contract, General Electric Co., Equitable Bldg., Sydney, N. S. W.	June 28, 1901
MACFADDEN, CARL K.	Consulting Engineer, Geneva, Ind.	Sept. 27, 1892
MACGREGOR, WILLARD H.	Westinghouse Electric & Mfg. Co., 120 Broadway; residence, 30 West 24th St., New York City.	Jan. 20, 1897
MACLEOD, GEORGE	[Address unknown.]	Aug. 5, 1896
MACOMBER, IRWIN JOHN	Professor of Electrical Engineering Armour Institute of Technology, residence, 422 34th Street, Chicago, Ill.	Mar. 28, 1900
MAGEE, LOUIS J.	Electrical Engineer, Director, der Union Elektricitats Gesellschaft, Grosse Quer Allee 1., Berlin, Germany.	April 2, 1889
MAGIE, LOUIS DEWITT	Works Engineer, Canadian General Electric Co., Peterborough, Ont.	Sept. 27, 1901
MAGNUS, BENJAMIN	Electrical Engineer, Ref. Dept., Anaconda Copper Mining Co., Anaconda, Mont.	Jan. 24, 1900
MAHONEY, JAMES J.	Engineer General Electric Co., 44 Broad St., New York City.	May 17, 1898
MAKI, HEIICHIRO	Chief Engineer, Hoshyu Traction Co., Beppu, Oitaken, Japan.	Aug. 5, 1896
MANSFIELD, R. H. Jr.,	Eastern Manager of the Cutler-Hammer Mfg. Co., Westfield, N. J.	Sept. 28, 1898
MARBURG, LOUIS C.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Feb. 28, 1902
MARSH, CHAS. J.	General Manager, Eastern and Northeastern Sales Departments, Standard Underground Cable Co., 56 Liberty St., New York City.	May 21, 1901
MARSH, HARRY BOWMAN	Secretary, The Sanborn & Marsh Electric Co.; residence, 1131 North Illinois St., Indianapolis, Ind.	Mar. 28, 1900
MARSHALL, CLOYD, *E. E.*	Engineer, C. W. Hunt Co.; residence, 98 Richmond Terrace, West New Brighton, S. I., N. Y.	April 25, 1900

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Name.	Address.	Date of Election.
MARTIN, FRANK	Electrician, Dept. Yards and Docks, New York Navy Yard; residence, 234 Adelphi Street, Brooklyn, N. Y.	Oct. 21, 1890
MARTIN JOHN	Agent, Stanley Electric M'fg. Co., 33 New Montgomery St., San Francisco, Cal.	July 27, 1898
MARTIN, T. COMMERFORD	(*Past-President.*) Editor, *The Electrical World and Engineer*, 114 Liberty St., N. Y. City.	April 15, 1884
MASON, HOBART, *B.S.*, *E.E.*	Graduate Student, Polytechnic Institute; residence, 432 Greene Ave., Brooklyn, N. Y.	June 28, 1901
MASSON, RAYMOND S.	Supt., Independent Electric Light and Power Co., 321 Market St., San Francisco, Cal.	Apr. 26, 1899
MATHER, EUGENE HOLMES	Manager Cumberland Ill. Co. and Portland Electric Light Co., Portland, Me.	April 28, 1897
MATTHEWS, CHARLES P.	Associate Professor, Electrical Engineering, Purdue University, residence, Thornell St., Lafayette, Ind.	May 16, 1893
MAXIM, HIRAM PERCY	Engineer, Vehicle Motor Department, Westinghouse E. & M. Co., Pittsburg, Pa.	Jan. 3, 1902
MAXWELL, EUGENE	c/o. Snoqualmie Falls Power Co., Seattle, Wash.	Aug. 5, 1896
MAURO, PHILIP	Counsellor-at-Law in Patent Causes (Pollock & Mauro), 620 F. St., Washington, D. C.	Dec. 21, 1892
MAYER, MAXWELL M.	Maxwell M. Mayer Electric Co., Electrical Engineers and Mfrs. of Dynamos and Motors, 216 Centre St.; residence, 226 East 118th St., New York City.	Feb. 27, 1895
MCALLISTER, ADDAMS STRATTON	Assistant in Physics, Cornell University; residence, 106 Catherine St., Ithaca, N. Y.	Mar. 28, 1902
MCBERTY, FRANK R.	Telephone Engineer, Western Electric Co., Chicago, Ill.; residence, Evanston, Ill.	April 26, 1901
MCCARTER, ROBERT D. JR.	Electrical Engineer, General Electric Co., 110 Cannon St., London, E. C.	May 16, 1899
MCCARTHY, E. D.	McCarthy Bros. & Ford, 45 North Division St.; residence, 382 West Ferry Street, Buffalo, N. Y.	Nov. 18, 1896
MCCARTY, FRANCIS ALEXANDER	Electrical Engineer, Noyes Bros., Yaralla Chambers, 109 Pitt St., Sydney, Australia.	June 28, 1901
MCCLENATHAN, ROBERT	Mechanical and Electrical Engineer, With General Electric Co., Schenectady, N. Y.	May 16, 1899
MCCLUER, CHAS. P.	Wm. R. Trigg Co., Shipbuilders, Richmond, Va.	Apr. 22, 1896

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Name.	Address.	Date of Election.
McCLURE, WILLIAM J.	Associated with H. D. Brown, Electrical Engineers and Contractors, residence, 259 West 52nd St., New York City.	Apr. 25, 1900
McCLURG, W. A.	Manager, Electrical Dept., Plainfield Gas and Electric Light Co., 217 West 2d St., Plainfield, N. J.	Dec. 20, 1893
McCONAHEY, WILLIAM M.	Electrical Engineer, British Westinghouse Electric Mfg. Co., Ltd., Trafford Park, Manchester, Eng.	Sept. 27, 1901
McCREARY, J. L.	Constructing Engineer, District Railway Co., Mexico City.	Feb. 28, 1900
McELROY, JAMES F.	Consulting Engineer, Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	Nov. 15, 1892
McGRATH, WILLIAM HENRY	Electrical Engineer, with Stone & Webster, 93 Federal St., Boston; residence, 27 Pleasant St., Quincy, Mass.	Mar. 28, 1902
McGRAW, JAMES H.	President, McGraw Publishing Co., 114 Liberty St., New York City; residence, Madison. N. J.	Sept. 27, 1901
McKISSICK, A. F.	Engineer, Pelzer Manufacturing Co., Pelzer, S. C.	Feb. 16, 1892
McLAIN, RALPH CLAPP	Assistant Engineer, Rapid Transit Subway Construction Co., 21 Park Row, residence, 170 W. 59th St, New York N. Y.	Aug. 23, 1899
McLIMONT, A. W.	Engineer, Federal Electric Co., 141 Broadway, New York City.	July 26, 1900
McVAY, H. D.	Supt. Overton M'f'g. and Engineering Co., 111 E. 7th St., Topeka, Kan.	Feb. 28, 1900
MEADOWS, HAROLD GREGORY	Associate Engineer (Elec.) with Newcomb Carlton, 109 White Building; residence, 238 Elmwood Ave., Buffalo, N. Y.	Sept. 23, 1896
TER MEER, HENRY CHARLES	Electrical Engineer, Eng. Dept., New York Telephone Co.; residence, 930 Hudson St., Hoboken, N. J.	Feb. 28, 1901
MEREDITH, WYNN	Electrical Engineer, Benjamin, Hunt, and Meredith, 331 Pine St., San Francisco, Cal.	Jan. 17, 1893
MERRILL, E. A.	Manager, New York Office, McIntosh, Seymour & Co., 26 Cortlandt St., New York City.	Sept. 20, 1893
MERRILL, JOSEPH F.	Professor of Physics and Electrical Engineering, University of Utah, Salt Lake City, Utah.	May 21, 1901
MERRILL, JOSIAH L.	Electrical Engineer, c/o. General Railway Supply Co., Park Bldg, Pittsburg, Pa.	Sept. 25, 1895
MERZ, CHAS. H.	28 Victoria St., Westminster, London S. W., and 1 Mosley St., Newcastle-on-Tyne, England.	Sept. 25, 1895

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Name.	Address.	Date of Election
MEYER, HANS S.	Electrical Engineer, Alleestrasse 7D Hannover, Germany.	July 27, 1889
MEYER, JULIUS	Consulting Engineer, 115 Broadway, Room 124, New York City.	Oct. 25, 1898
MIDDLETON, A. CENTER	General Electric Co., 420 W. 4th St., Cincinnati, O.	May 16, 1899
MILES, J. WALTER	Electrical Engineer, Westinghouse Electric and M'f'g Co., Irwin, Pa.	April 25, 1902
MILLER, ALPHONSUS JOSEPH	Laboratory Assistant, Western Electric Co., 463 West St; residence, 161 Newark St., Hoboken, N. J.	Mar. 28, 1902
MILLER, DWIGHT DANA	Salesman, Westinghouse Electric and M'f'g Co., 120 Broadway, New York City; residence, Upper Montclair, N. J.	Apr. 25, 1902
MILLER, GEORGE E.	Assistant to 2d Vice-President, Westinghouse E. & M. Co.; residence, 4911 Centre Ave., Pittsburg, Pa.	Feb. 28, 1902
MILLER, HERBERT S.	Electrical Engineer, Diehl Mfg. Co.; residence, 1025 E. Jersey St., Elizabeth, N. J.	Mar. 22. 1899
MILLER, KEMPSTER B.	Engineer Kellogg Switchboard and Supply Co., Congress and Green St., residence, 2060 Kenmore Ave., Chicago, Ill.	Sept. 28, 1898
MILLER, WALTER H.	Manager Record Dept. (Phonograph), with Thomas A. Edison; residence, 28 Mt. Vernon St., Orange, N. J.	Sept. 27, 1901
MILLER, WM. C., *M. S.*	Electrical Engineer, 3 South Hawk St., Albany, N. Y.	Oct. 21, 1890
MISAKI, SEIZO	Chief Engineer and Superintendent Hanshin Elec. Railway Co., Nishinomiyo, Hiogo Ken, Japan.	Dec. 27, 1899
MITCHELL, SIDNEY Z.	Manager, Portland Office, General Electric Co., Worcester Building, Portland, Ore.	Nov. 12, 1889
MONRATH, GUSTAVE	Engineer and Superintendent, Grace and Hyde Engineering Co., 7 E. 42d St., New York City.	Apr. 26, 1901
MONTAGU, RALPH LECHMERE	Continental Gold Dredging Co., Oroville, Cal.	Feb. 26, 1896
MOODY, VIRGINIUS DANIEL	General Electric Co.; residence, 427 Smith St., Schenectady, N. Y.	Dec. 27, 1899
MOORE, JOHN PEABODY	Engineering Department, General Electric Co., Box, 389, Schenectady, N. Y.	Apr. 25, 1900
MORA, MARIANO LUIS	General Electric Co., 44 Broad St., New York City.	Mar. 20, 1895

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Name.	Address.	Date of Election.
MORDEY, WM. MORRIS	Consulting Electrician, 82 Victoria St., Grosvenor Mansions. Westminster, London, Eng.	Sept. 22, 1891
MOREHEAD, J. M.	Engineer, Union Carbide Co., 157 Michigan Ave., Chicago, Ill.	Mar. 28, 1900
MOREHOUSE, H. H.	Morehouse and Morrill. General Electric Installation and Contracting Work, Apartado No 44, Quezaltenango, Guatemala, C. A.	Feb. 21, 1894
MORGAN, CARL LEON	Engineer, Purchasing Dept., Edison Electric Illuminating Co., 3 Head Place; residence, 25 St. Cecilia St., Boston, Mass.	Jan. 24, 1902
MORGAN, GODFREY	General Supt., The Youngstown & Sharon Street Railway Co.; residence, Phelps St., Youngstown, O.	Oct. 25, 1901
MORGAN, JACQUE L.	City Electrician, City Hall, residence, 1702 Locust St., Kansas City, Mo.	Jan. 26, 1898
MORLEY, EDGAR L.	Sup't Hatzel & Buehler, 114 5th Ave., New York City.	Sept. 25, 1895
MORRILL, EDWARD FRANCIS	Engineering Department, The New York and New Jersey Telephone Co., 81 Willoughby St; residence, 18 Willoughby Ave., Brooklyn, N.Y.	Feb. 28, 1902
MORRISON, J. FRANK	Manager, The Northern Electric Co. 15 South St., Baltimore, Md.	April 15, 1884
MORRISON, WILLIAM JAMES, JR.	Stock Broker, Consolidated Exchange, 60 Broadway, New York City; also Experimental Electro-Chemistry, Ridgefield Park, N. J.	Sept. 27, 1901
MORTIMER, JAMES D.	Instructor in Electrical Engineering, University of California, Mechanics' Building, Berkeley, Cala.	Mar. 28, 1900
MORTLAND, JAMES A.	Sergeant 12th Co., U. S. V., Signal Corps, Official Photographer, 3d Army Corps, Montezuma, Iowa.	Feb. 23, 1898
MORTON, HENRY, *Ph.D.*	President of Stevens Institute of Technology, Hoboken, N. J.	May 24, 1887
MOSCHKOWITSCH, MEERS S.	Preobrajenska, 53, Odessa, Russia.	Jan. 9, 1901
MOSES, PERCIVAL ROBERT, *E. E.*	Electrical Engineer, 35 Nassau St.: residence, 46 West 97th St., New York City.	Dec. 19, 1894
MOSSCROP, WM. A., *M.E*	Electtical Engineer, 47 Brevoort Place, Brooklyn, N. Y.	May 7, 1889
MUDGE, ARTHUR LANGLEY	Electrical Engineer, Stanley Electric Mfg. Co., Pittsfield, Mass.	Mar. 22, 1901
MULLIGAN, WALTER LYON	Assistant Manager, United Electric Light Co., Box 812 Springfield, Mass.	Feb. 28, 1902
MULLIN, E. H.	General Electric Co., 44 Broad St., residence, 1 West 102nd Street, New York, N. Y.	May 16, 1899

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Name.	Address.	Date of Election.
MURPHY, EDWIN J.	Assistant Engineer, General Electric Co.; residence, 28 Atlantic Terrace, Lynn, Mass.	Mar. 28, 1904
MURPHY, GEORGE R.	Engineer, Operating Dept., The Electric Storage Battery Co.; residence, 65 W 93d St., New York City.	Apr. 25, 1902
MURPHY, JOHN McL.	[Address unknown.]	Oct. 26, 1898
MURRAY, THOS. E.	Second Vice-President and General Manager, New York Edison Co., 55 Duane St., New York City.	May 21, 1901
NAMBA, M.	Professor of Electrical Engineering, University of Kioto, Kioto, Japan.	Apr. 26, 1899
NAPHTALY, SAM L.	Asst. Engineer, San Francisco Gas & Electric Co., 229 Stevenson St.; residence, 2404 Broadway, San Francisco, Cal.	Aug. 23, 1899
NEILSON, JOHN	Larchmont, N. Y.	May 18, 1897
NESBIT, JOSEPH NEWTON GRAY	Superintendent Winding Dept., Warren Electric Mfg. Co., Plum St., Sandusky, Ohio.	Nov. 22, 1901
NEURATH, MORRIS M.	Electrical Engineer, A. & N. Mfg. Co., 165 Broadway, N. Y.	Feb. 26, 1900
NEWBURY, F. J.	Manager Insulated Wire Department, John A. Roebling's Sons Co., Trenton, N. J.	Sept. 23, 1896
NEWELL, FRANK CLARENCE	Consulting Electrical Engineer, Westinghouse Air Brake Co; residence, 526 Wallace Ave., Wilkinsburg, Pa.	Jan. 3, 1902
NEWMAN, FRED JACOB	Electrical Engineer, Westinghouse Electric and Mfg. Co; residence, 337 Atwood St., Pittsburg, Pa.	Sept. 27, 1901
MURPHY, EDWIN J.	Assistant Engineer, General Electric Co.; residence, 28 Atlantic Terrace, Lynn, Mass.	Mar. 28, 1902
NICHOLS, LOUIS CHARLES	Electrical Engineer, The Converse Transformer Co; residence, 421 S. Highland Ave., Pittsburg, Pa.	Feb. 28, 1902
NICHOLSON, SAMUEL L.	With Westinghouse Elec. & M'fg. Co., 120 Broadway, New York; residence, 820 President St., Brooklyn, N. Y.	July 26, 1900
NIESZ, HOMER ELDREDGE	Assistant to General Superintendent, Chicago Edison Co., 139 Adams St.; residence, Hyde Park Hotel, Chicago, Ill.	Oct. 25, 1901
NIMIS, ALBERT A.	Electrical Contractor, Nimis & Nimis, 59 East 5th Street, St. Paul, Min. and N. E. cor. 82d St. & Lexington Ave., N. Y. City.	Aug. 13, 1897
NOCK, GEO. W.	General Manager, H. D. & H. H. R. R., Danbury, Conn.	Aug. 5, 1896
DR NORDWALL, CHARLES FLESCH,	Manager of the Export Department, Allgemeine Elektricitats-Gesellschaft, 22 Schiffbauerdamm, Berlin, N. W. Germany.	Sept. 27, 1892

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Name.	Address.	Date of Election.
NORTHRUP, EDWIN FITCH	Chief Engineer (Electrical), Rowland Telegraph Co.; Office, 710 North Howard St., Baltimore, Md.	Sept. 27, 1801
NOXON, C. PER LEE	Manufacturer, High-Frequency X-Ray Apparatus, Dynamos and Motors, 500 East Water Street, Syracuse, N. Y.	Oct. 17, 1894
NUNN, RICHARD J., *M. D.*	Physician, 5 York St. East, Savannah, Ga.	July 12, 1887
NYHAN, J. T.	Superintendent and Electrician, Macon Electric Light and Railway Co., Macon, Ga.	Feb. 27, 1895
O'BRIEN, ALBERT DALLAM	Assistant N. Y. & N. J. Telephone Co., 81 Willoughby St.; residence, 17 Monroe Place, Brooklyn, N. Y.	Nov. 22, 1901
OCKERSHAUSEN, H. A.	Electrical Engineer, 65 Madison Ave., Jersey City, N. J.	Sept. 6, 1887
O'DONOVAN, LEO. J.	Student, Columbia University; residence, 302 W. 72d St., New York City.	Apr. 25, 1902
OFFINGER, MARTIN HENRY	Head of Electro-Mechanical Dept., Buffalo Commercial & Electro Mechanical Institute; residence, 544 Plymouth Ave., Buffalo, N. Y.	Mar. 28, 1900
OFFUTT, ANDERSON, *B.S.*, *E.E.*	Assistant Electrician, South Eastern Tariff Ass'n. Care Underwriters Inspection Bureau, New Orleans, La.	May 15, 1900
OI, SAITARO	Chief Engineer to the Bureau of Posts and Telegraphs. The Ministry of Communications, Tokyo, Japan.	Dec. 28, 1898
OLIVETTI, CAMILLO	Ingegnere Industriale, Ivrea, Italy.	Oct. 17, 1894
OOLGARDT, J. J.	Electrical Engineer, (Foreign Dept.) General Electric Co.; residence, Edison Hotel, Schenectady, N. Y.	April 25, 1900
ORMSBEE, ALEX. F.	Electrical Engineer, with N. Y. and N. J. Telephone Co., 81 Willoughby St.; residence, 183 Joralemon St., Brooklyn, N. Y.	June 27, 1895
OSBORNE, LOVALL ALLEN	Manager of Works, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Oct. 18, 1893
OSBORNE, MARSHALL	Engineer in charge of Contracts, The British Thomson-Houston Co., 83 Cannon St., London, Eng.	April 25, 1900
OSTERBERG, MAX, *E.E.*, *A.M.*	Consulting Engineer, and Electrical Expert, Bowling Green Building, New York City.	Jan. 17, 1894
O'SULLIVAN, M. J.	Superintendent, Electric Light, B. & O. R. R. Co., Sylvan Ave. near Hazelwood, Pittsburg, Pa.	Mar. 20, 1895
OTTEN, DR. JAN D.	Director, Batavia Electrische Tram-Maatschappij, Van Baerlstraat 80, Amsterdam, Holland.	Nov. 18, 1890
PAGE, A. D.	Assistant Manager, General Electric Co. Lamp Works, Harrison, N. J.	Jan. 19, 1892

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Name.	Address.	Date of Election.
PALMER, D. ALONSO	Superintendent, Compania Anonima de Redes Telefonicas de Ponce; Box 135, Ponce, Porto Rico.	Oct. 25, 1901
PARKE, RODERICK J.	Consulting Electrical Engineer, 409 Temple Bldg., Toronto, Canada.	July 26, 1900
PARKER, HERSCHEL C.	Instructor in Physics, Columbia University, New York City; residence, 21 Fort Green Pl., Brooklyn, N. Y.	April 19, 1892
PARKER, LINDSAY R.	Residence, 345 State St., Brooklyn, N. Y.	Sept. 27, 1901
PARKHURST, CHARLES WILLIAM	Superintendent of Electrical Department, Cambria Steel Co., Johnstown, Pa.	Sept. 27, 1901
PARMLY C. HOWARD, *S.M., E.E.*	College of the City of New York, 17 Lexington Ave.; residence, 524 W. 114th St., New York City.	Feb. 21, 1893
PARRY, EVAN	Engineer, c/o. H F. Parshall, 8 Princes St , Bank; residence, Sunningdale, 10 Fitzgerald Ave., Mortlake, London, S. W., England.	Sept. 25, 1895
PARSELL, HENRY V. A.	Electrical and Mechanical Designing and Experimental Work, 129 W. 31st St , residence, 31 E. 21st St., New York City.	Nov. 12, 1889
PARSHALL, AUGUST	Commercial Engineer, Supply Dept. General Electric Co., 44 Broad St., New York City.	Oct. 24, 1900
PARSONS, ISAAC DAYTON	Assistant in Electrical Engineering Dept., Columbia University; residence, 236 W. 55th St., New York City.	Jan. 24, 1902
PATTERSON, GEORGE WASHINGTON, JR.	Junior Professor of Electrical Engineering, University of Michigan, 814 South University Ave., Ann Arbor, Mich.	Sept. 27, 1901
PATTON, PRICE I.	The Bartram, 33d and Chestnut St., Philadelphia, Pa.	Mar. 20, 1895
PEARSON, FRED'K J.	3841 West 63d Place, Chicago, Ill.	July 27, 1898
PECK, EDWARD F.	360 Pearl St.; residence, 1246 Pacific St., Brooklyn, N. Y.	May 20, 1890
PIERCE, ALFRED LAWRENCE	Superintendent, General Manager and E. E. Borough Electric Works; residence, 102 N. Whittlesey Ave., Wallingford, Conn.	Mar. 28, 1902
PEIRCE, ARTHUR W. K.	Consulting Electrical Engineer to the Consolidated Gold Fields of South Africa, Ltd., Box 217, Germiston, Transvaal.	June 27, 1895
PENDELL, CHAS. WILLIAM	Electric Signal Inspector, A. T. & S. F. Ry., 809 Topeka Ave., Topeka, Kansas; residence, Cleburne, Texas.	Nov. 22, 1899

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Name.	Address.	Date of Election.
PERKINS, FRANK C.	Electrical Engineer, 126 Erie Co. Bank, 655 Prospect Ave., Buffalo, N. Y.	Oct. 21, 1890
PETICOLAS, SHERMAN GOODWIN	District Electrical Engineer, Wagner-Bullock Electric Mfg. Co's., St. Louis and Cincinnati.	Sept. 27, 1901
PETTY, WALTER M.	Superintendent Fire Alarm Telegraph, Rutherford, N. J.	May 16, 1893
PFEIFFER, ALOIS J. J.	Engineer, 22a College Hill, London, E. C., England.	Jan. 24, 1900
PFUND, RICHARD	Manager New York Herald Wireless Telegraph Station, Siasconset, Nantucket, Mass.	April 18, 1893
PHELPS, WM. J.	Manager, The Phelps Co., Makers Hylo Incandescent Lamp, 33 State St., Detroit. Mich.	Mar. 25, 1896
PHILBRICK, B. W.	Electrical Engineer for J. J. Astor, Rhinecliff, N. Y.	May 15, 1894
PHILLIPS, EUGENE F.	President, American Electrical Works, Phillipsdale, R. I.	July 13, 1889
PHILLIPS, ELLIS LAURIMORE	Engineer, Westinghouse, Church, Kerr & Co., 26 Cortlandt St; residence, 11 West 103d St., New York City.	Mar. 28, 1902
PHILLIPS, LEO A.	Oakmore, Pa.	Mar. 21, 1894
PILLSBURY, CHAS. L.	Consulting Electrical Engineer, Andrus Building, Sec'y State Board of Electricity, Minneapolis, Minn.	Aug. 13, 1897
PIRTLE, CLAIBORNE,	Sales Agent for North Carolina, General Electric Co., Box 301, Greensboro, N. C.	Mar. 28, 1902
PITCHER, FRANK HENTY	Chief Engineer, Montreal Water and Power Co., 62 Imperial Building, Montreal, P. Q.	June 28, 1901
POIRIER, ALFRED E.	Manager, N. Y. & N. J. Tel. Co., 8 Erie St., Jersey City, N. J.; residence, 29 W. 21st St., N. Y. City.	May 21, 1901
POMEROY, WILLIAM D.	The Bullock Electric Mfg. Co., Cincinnati, Ohio.	Mar. 22, 1899
POOLE, CECIL P.	Editor *American Electrician*, 114 Liberty St., residence, 163 W. 84th St., New York City.	Jan. 3, 1888
POOLE, CHARLES OSCAR	Superintendent Electrical Dept., Standard Electric Co. of California, Crocker Bldg.; residence, 452 Bryant St., San Francisco, Cal..	Jan. 24, 1900
POPE, HENRY WILLIAM	Acting General Manager, Bell Telephone Co., of Buffalo; residence, 455 Richmond Ave., Buffalo, N.Y.	Mar. 23, 1898
POPE, RALPH WAINWRIGHT	Secretary to the American Institute of Electrical Engineers, 95 Liberty St., (Telephone, 2199 Cortlandt), New York City; residence, 570 Cherry St., Elizabeth, N. J.	June 2, 1885
PORTER, H. HOBART, JR.	Sanderson & Porter, 31 Nassau St., New York; residence, Lawrence, L.I.	Mar. 25, 1896

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Name.	Address.	Date of Election.
POTT, ARTHUR HENRY	Consulting Engineer, with Preece & Cardew; residence, 81 Cornwall Gardens, S. W., Queensgate, London, England.	Nov. 22, 1901
POTTER, HENRY NOEL	510 West 23d St., New York City; residence, Orchard Place, Rochelle Park, New Rochelle, N. Y.	Sept. 19, 1894
POWELL, EDWIN BURNLEY	Meter Tester. The New York Edison Co., 55 Duane St., New York City.	May 21, 1901
POWELL, PERCY HOWARD	*M. E.*, Bridgeport Brass Co.; residence, 157 Coleman St., Bridgeport, Conn.	Sept. 25, 1895
POWELSON, WILFRED VAN NEST,	Government Inspector, Electrical Appliances; Lieutenant U. S. Navy, Navy Yard, Brooklyn, N. Y.	Jan. 24, 1900
PRATT, WILLIAM HEMMENWAY	Designing Engineer, General Electric Co.; residence, 60 Eastern Ave, Lynn, Mass.	Jan, 3, 1902
PRICE, CHAS. W.	Editor the *Electrical Review*, 13 Park Row, New York City; residence, 223 Garfield Place, Brooklyn, N. Y.	Sept 19, 1894
PRICE, EDGAR F.	Works Manager, Union Carbide Co., residence, 625 Buffalo Ave., Niagara Falls, N. Y.	June 27, 1895
PRICE, NORMAN I.	General Electric Co.; residence, 1 State St., Schenectady, N. Y.	Feb. 28, 1902
PRINCE, J. LLOYD	The New York Edison Co., New York City; residence, 868 Flatbush Ave., (Flatbush Station), Brooklyn, N. Y.	Feb. 27, 1895
PROCTOR, THOS. L.	Marine Electrical Equipment, 39 Cortlandt St., New York; residence, Elmhurst, L. I., N. Y.	April 18, 1894
PROSSER, HERMAN A.	Manager, De Lamar Copper Refining Works, Cartaret, N J.; residence, 415 North Broad St., Elizabeth, N. J.	Jan. 26, 1898
PUPIN, DR. MICHAEL I.	Adjunct Professor in Mechanics, Columbia University; residence, 280 North Broadway, Yonkers, N. Y.	Mar. 18, 1890
RADTKE, ALBERT AUGUSTUS	Instructor of E. E. and Physics, R. I. College of Agriculture & Mechanic Arts, Kingston, R. I.	Mar. 28, 1902
RAMSEY, HARRY NATHAN	Draughtsman, with Taylor Signal Co., 32 Wells St., Buffalo; residence, 311 East Henley St., Olean, N. Y.	May 16, 1899
RANSON, ALLEN EDWARD	Engineer and Salesman, Westinghouse E. & M. Co., 314 Occidental Ave., Seattle, Wash.	Jan. 3, 1902
RANDALL, JOHN E.	Columbia Incandescent Lamp Co., 1910 Olive St., St. Louis, Mo.	May 7, 1889
RANDOLPH, L. S.	Professor of Mechanical Engineering, Blacksburg, Va.	Feb. 21, 1893

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Name.	Address.	Date of Election.
RANDOLPH, MERVYN PAUL	District Office Manager, Westinghouse E. & M. Co., 314 Occidental Ave., Seattle, Wash.	Jan. 24, 1902
RATHENAU, ERICH	Electrical Engineer, Allg. Elektricitats Gesellschaft, Berlin, Germany.	Nov. 20, 1895
RAUB, CHAS. B.	Electrical Engineer, Thames Electric Co., New London, Conn.	Nov. 22, 1899
RAY, WILLIAM D.	Electrical Engineer, Detroit Construction Co., 1201 Chamber of Commerce Building, Detroit, Mich.	Sept. 27, 1892
READ, ROBERT H.	Patent Attorney, General Electric Co., Schenectady, N. Y.	Jan. 19, 1892
VON RECKLINGHAUSEN, MAX	With Mr. George Westinghouse, 510 West 23d St.; residence, 11 East 24th St., New York City.	Jan. 24, 1902
DEREDON, CONSTANT	Consulting Engineer. [Address unknown.]	May 18, 1897
REED, CHAS. J.	Electrician, 3313 N. 16th St., Philadelphia, Pa.	Mar. 5, 1889
REED, HARRY D.	Superint'd't Bishop Gutta Percha Co., 420 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	Sept. 19, 1894
REED, HENRY A.	Secretary and Manager, Bishop Gutta-Percha Co., 422 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	June 4, 1889
REED, WALTER WILSON	Electrical Engineer in charge of the electrical work of new plant Citizen Electric Light and Power Co., Houston, Texas.	April 26, 1899
REICHMANN, FRITZ	Ryerson Physical Laboratory, University of Chicago, Chicago, Ill.	Mar. 23, 1898
REID, EDWIN S.	General Sup't of Construction, National Conduit and Cable Co, 23 College Hill, Cannon St., E. C., London, Eng.	Feb. 26, 1896
REID, WILLIAM	Switchboard Engineer, N. W. Telephone Exchange Co., Tel. Bldg., Minneapolis, Minn	May 21, 1901
REILLY, HARRY WINNE	J. G. White & Co., Monroe, Mich.	Jan. 3, 1902
REILLY, JOHN C.	General Supt., N. Y. & N. J. Tel. Co., 81 Willoughby St., Brooklyn, N. Y.	April 15, 1884
REMSCHEL, CESAR WILHELM AUGUST	G. P. O., San Rafael, Cal.	Feb. 28, 1902
RENNARD, JOHN CLIFFORD, *A. B. E. E.*	Asst. Chief Engineer, New York Telephone Co., 15 Dey St., New York City.	Jan. 16, 1895
RENSTROM, FRANS OSCAR	Superintendent, The Regla Power Co., Apartado 95, Pachuca, Mexico.	Feb. 28, 1900
REUTERDAHL, ARVID	President and Chief Engineer, The Reuterdahl Electric Co.; residence, 366 Willard Ave., Providence, R. I.	Nov. 22, 1901
RICE, ARTHUR L.	Asst. to Secretary, A. S. M. E., 12 W. 31st St., New York City; residence, 230 East 11th St., Brooklyn, N. Y.	Oct. 21, 1896

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Name.	Address.	Date of Election.
RICE, MARTIN P.	Chief of Publication Bureau, General Electric Co., Schenectady, N. Y.	May 21, 1901
RICH, FRANCIS ARTHUR	Manager, Woodstock G. M. Co., Karangahake, Auckland, New Zealand.	Jan. 20, 1897
RICHARDS, CHAS. W.	C. W. Richards & Co., 178 Devonshire St, Boston; residence, Needham, Mass.	Sept. 23, 1896
RICHEY, ALBERT S.	Electrical Engineer, Union Traction Co. of Indiana, 215 W. 9th St., Anderson, Ind.	May 18. 1897
RICHTBERG, HERMANN ANDREAS	Electrical Engineer, Westinghouse Electric and Mfg. Co.; residence, 205 West 41st St., New York City.	Sept. 27, 1901
RIDEOUT, ALEXANDER C.	*LL. D.*, Consulting Electrical and Mechanical Engineer, Rideout & Gage, 101 Randolph St., Chicago, Ill.	Aug. 5, 1896
RIPLEY, WM. HOWE	Ripley & Arendt, 24 Murray St.; residence, 17 W. 123d St., New York City.	Feb. 17, 1897
ROBERSON, OLIVER R.	Electrician, Western Union Telegraph Co., 195 Broadway; P. O. Box 856, New York City.	Dec. 20, 1893
ROBERTS, ALLEN DAVIDSON	Electrician, 12½ King St., Kingston, Jamaica.	Nov. 22, 1899
ROBERTSON, JAS. MCCALLUM	Superintendent, Power Department, The Royal Electric Co., 94 Queen St., Montreal, P. Q.	Apr. 26, 1901
ROBINSON, ALMON	Webster Road, P. O. Box 943, Lewiston, Me.	Sept. 6, 1887
ROBINSON, ARTHUR L.	Manager, Eclipse Mine, Auburn (R. F. D.) Placer Co., Cal.	May 15, 1900
ROBINSON, DWIGHT PARKER	Assistant General Manager, The Seattle Electric Co., 815 2nd Ave., Seattle, Wash.	Sept. 25, 1895
ROBINSON, FRANCIS GEORGE	With Metropolitan Street Railway Co.; residence, Hotel Richelieu, 114th St. & Fifth Ave., New York City.	Nov. 21, 1894
ROBINSON, GEO. P.	Ass't Supt. L. D. Service, The Wisconsin Telephone Co., 498 Milwaukee St., Milwaukee Wis.	May 16, 1899
ROCKWOOD, DWIGHT CARRINGTON	Student, Westinghouse Electric and Mfg. Co., Pittsburg; residence, 516 Kelly Ave., Wilkinsburg, Pa.	Mar. 22, 1901
RODGERS, ASHMEAD GRAY	General Superintendent, Eddy Electric Mfg. Co., Windsor. Conn.	Sept. 27, 1901
ROEBLING, FERDINAND W.	Manufacturer of Electrical Wires and Cables, Trenton, N. J.	June 8, 1887

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Name.	Address.	Date of Election.
ROGERS, NELSON	Electrician, Sawyer-Man Electric Co. Experimental Dept., 510 W. 23d St., New York City; residence, Mt. Vernon, N. Y.	May 21, 1901
ROPER, DENNEY W.	Electrical Engineer, with Chas. H. Ledlie, 920 Rialto Bldg.; residence, 3400 Morgan St., St. Louis, Mo.	June 6, 1893
ROSEBRUGH, THOMAS REEVE	Lecturer in Electrical Engineering, School of Practical Science, 666 Spadina Ave., Toronto, Ont.	June 26, 1891
ROSENBAUM, WM. A.	Attorney in Patent Cases, Nassau-Beekman Building, 140 Nassau St., Telephone, 2977 John, New York City.	Jan. 3, 1889
ROSENBERG, E. M., *M. E.*	Residence, 138 W. 85th St., New York City.	Oct. 21, 1890
ROSENBUSCH, GILBERT	Royal Societies Club, London, England.	Sept. 28, 1898
ROSS, TAYLOR WILLIAM	Newport News Shipbuilding & Dry Dock Co.; residence, 114 34th St., Newport News, Va.	Mar. 25, 1896
ROSSI, HAROLD J.	San Marten Texmelucan, Ede Pueblo, Mexico.	Oct. 24, 1900
ROWLAND, ARTHUR JOHN	Professor of Electrical Engineering, Drexel Institute; residence, 4510 Osage Ave., Philadelphia, Pa.	Sept. 19, 1894
RUCKGABER, ALBERT FELIX	Rapid Transit Subway Construction Co.; residence, 373 Carlton Ave., Brooklyn, N. Y.	Nov. 22, 1901
RUFFNER, CHARLES SHUMWAY	Electrician, The Telluride Power Co., Telluride; residence, Vance Junction, Colorado.	Feb. 28, 1902
RUGG, WALTER S.	Engineer, Westinghouse Elec. & Mfg. Co., 120 Broadway; residence, 225 W. 83d St., New York City.	Mar. 28, 1902
RUSHMORE, SAMUEL W.	Proprietor, Rushmore Dynamo Works. 24 Morris St., Jersey City, N. J.	Mar. 28, 1900
RUSSEL, EDGAR	Captain Signal Corps, U. S. A., War Department, Washington, D. C.	Nov. 22, 1901
RUSSELL, H. A.	Sales Agent, General Electric Co., residence, 302 Laurel St., San Francisco, Cala.	Nov. 22, 1899
RUSTIN, HENRY	Chief Electrical and Mechanical Engineer of World's Fair, St. Louis, Mo.	Oct. 24, 1900
RUTHERFORD, WALTER	Manager Electric Traction Dep't, Dick Kerr & Co., Ltd., 110 Cannon St., London E. C., England.	Sept. 22, 1891
RYAN, WALTER D'ARCY	Engineer, General Electric Co., Lynn, Mass.	Jan. 24, 1902
RYDER, M. P.	Supt. of Bronx Dist., New York Edison Co., 140th St. and Rider Ave.; residence, 848 E. 163d St., New York City.	May 21, 1901

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Name.	Address.	Date of Election.
RYERSON, WM. NEWTON	Electrician, 74th St. Station, Manhattan Railway Co., 74th Street and East River; residence, 215 West 100th St., New York.	Aug. 23, 1899
SAGE, DARROW	In Testing Department, General Electric Co.; residence, 244 Union St., Schenectady, N. Y.	Sept. 27, 1901
SAGE, FREDERICK BRITTAN	Partner, F. B. Sage & Bro., 123 Liberty St., New York; residence, Hackensack, N. J.	May 21, 1901
SAGE, HENRY JUDSON	Sage & Co., Electrical Engineers, Rochester, Pa.	Dec. 20, 1893
SAHULKA, DR. JOHANN	Docent of Electrotechnics, Technische Hochschule, Vienna, Austria.	Dec. 20, 1893
SALTER, THOMAS FITCH	Designer and Inspector of Drawings, Western Electric Co., 57 Bethune St.; residence, 424 West 57th St., New York City.	May 21, 1901
SANBORN, FRANCIS N.	29 Wall St., New York City.	Nov. 24, 1891
SANDERSON, EDWIN N.	Of Sanderson & Porter, Engineers and Contractors, 31 Nassau St., New York City.	Oct. 17, 1894
SANVILLE, HENRY F.	Secretary and Electrical Engineer, Morris Electric Co., Splice and Terminal Co., 15 Cortlandt St.; residence, 213 W. 105th St., New York.	Feb. 28, 1901
SARGENT, HOWARD R.	Electrical Engineer, General Electric Co.; residence, 13 Park Ave., Schenectady, N. Y.	Mar. 25, 1896
SATHERBERG, CARL HUGO	Chief Engineer, The Midvale Steel Co., Nicetown, Phila., Pa.; residence 1752 N. 26th St., Philadelphia, Pa.	Aug. 5, 1896
SAWYER, WILLETS HERBERT	Engineer, Railway Engineering Department General Electric Co.; residence, 4 Gillespie St., Schenectady, N. Y.	Feb. 28, 1902
SAXELBY, FREDERICK	Electrical Engineer, Bullock Electric M'f'g. Co., 220 Broadway, New York; residence, 15 Whittlesey Ave., East Orange, N. J.	June 5, 1888
SAYLOR, FREDERICK ALEXANDER [Life Member.]	Care Charles G. Thrall, 15 O'Reilly St., Havana, Cuba.	Jan. 24, 1900
SCHILDHAUER, EDWARD	Engineering Department, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Nov. 22, 1901
SCHLOSSER, FRED. G.	Superintendent of Electric Dept., Laclede Gas Light Co., 411 N. 11th St. Louis, Mo.	Sept. 22, 1891
SCHMIDT, CHAS. J.	In Engineering Dept. as Telephone Engineer, Milwaukee Electric Railway and Light Co., Construction Dept., Milwaukee, Wis.	Jan. 9, 1901
SCHMIDT, LAMBERT	President, The Lambert Schmidt Tel. Mfg. Co., 325 Broadway (Telephone, 2727 Franklin), New York City; residence, 138 Schippen St., Weehawken, N. J.	Nov. 22, 1901

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Name.	Address.	Date of Election.
SCHOOLFIELD, FRANK ROBERT	Chief Engineer, Baltimore Smelting and Rolling Co., Canton; residence, 713 West Fayette St., Baltimore, Md.	May 16, 1899
SCHREITER, HEINR. *C. E.*	Counsellor and Attorney, 20 Nassau St., New York City.	Jan. 17, 1893
SCHUM, CHAS. H.	Electrical Engineer, with Bergmann Electromoteren and Dynamo Werke, Oudenarder Strasse, 23-30, Berlin, Germany.	Feb. 23, 1898
SCHURIG, EDWARD F.	City Electrician, The City of Omaha, 306 City Hall, Omaha, Neb.	Apr. 26, 1899
SCHIAFFINO, MARIANO L.	Chief Electrician, Compania de Luz Electrica, Guadalajara, Mexico.	Feb. 28, 1900
SCHROEDER, HENRY	Inspector, The New York Edison Co.; residence, 137 Madison Ave., New York, N. Y.	June 28, 1901
SCHWAB, MARTIN C.	Electrical Engineer, with Northern Electric Co., 15 South St.; residence, 1729 Madison Ave., Baltimore, Md.	Nov. 18, 1896
SCHWABE, WALTER P.	Superintendent Electrical Dept. Rutherford District, The Gas and Electric Co. of Bergen County, Rutherford, N. J.	May 19, 1896
SCHWEITZER, EDMUND OSCAR.	Electrical Inspector, Commonwealth Electric Co., 667 Lincoln Ave; residence, 1906 Oakdale Ave., Chicago, Ill.	Feb. 15, 1899
SCIDMORE, FRANK L.	Otis Elevator Co.; residence, 69 Ravine Ave., Yonkers, N. Y.	Dec. 18, 1895
SCOTT, WM. M.	Electrical Engineer. The Cutter Electrical and Mfg. Co., 1112 Sansom St., Philadelphia, Pa.; residence, 108 West Johnson St., Germantown, Pa.	June 23, 1897
SCRIBNER, CHARLES E.	Engineer, Western Electric Co., 259 South Clinton St., Chicago, Ill.	Mar. 28, 1902
SCUDDER, HEWLETT, JR.,	21 East 22d St., New York City.	Nov. 22, 1899
SEABROOK, HENRY HAMILTON	Sales Engineer, Westinghouse E. & M. Co., 1317 F St; residence, 822 Connecticut Ave., N. W., Washington, D. C.	Jan. 24, 1902
SEARING, LEWIS	Vice-President and General Manager, Denver Engineering Works Co., 924 Washington Ave., Denver, Col.	April 3, 1888
SEARLES, A. L.	Electrical Engineer, Fort Wayne Electric Works, Marquette Building, Chicago, Ill.	April 18, 1894
SEDGWICK, C. E.	Manager, The Hilo Electric Light Co. Ltd., Hilo, H. I.	Feb. 23, 1898
SEE, ALONZO B.	A. B. See Electric Elevator Co., 220 Broadway, New York City; residence, Lake Mahopac, N. Y.	Jan. 17, 1893

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Name.	Address.	Date of Election.
SERRELL, LEMUEL WM.	Mechanical and Electrical Engineer, 99 Cedar St., New York City; residence, Plainfield, N. J.	Nov. 1, 1887
SHAFFNER, S. C.	Supt. and Electrician. Electric Lighting Co. of Mobile, 306 St Anthony St., Mobile, Ala.	Aug. 13, 1897
SHARP, CLAYTON HALSEY	Test Officer, Lamp Testing Bureau, 14 Jay St., New York City; residence, 722 Highland Ave., Newark, N. J.	Feb. 28, 1902
SHAW, AUBREY NORMAN	Draughtsman, A. B. See Electric Elevator Co.; residence, 298 Carlton Ave., Brooklyn, N. Y.	Mar. 28, 1900
SHAW, HOWARD BURTON	Professor Electrical Engineering, Missouri State University, Columbia, Mo.	April 28, 1897
SHEARER, J. HARRY	Electrical Engineer, National Electric Light Co , Apartado, 639 Mexico City, Mexico.	Jan. 24, 1900
SHELDON, EDWARD ELLIS	Electrical Engineer, Hudson River State Hospital; residence, 47 Hudson Ave, Poughkeepsie, N. Y.	Apr. 25, 1902
SHEPARD, ROBERTO R.	Erecting Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	Jan. 24, 1900
SHERWOOD, EDGAR F.	Superintendent of Traffic, New York Telephone Co., 18th St. and Irving Place; residence, 59 Park Avenue, East Orange, N. J.	Mar. 28, 1902
SHOCK, THOS. A. W.	Electrical Engineer, York Haven Meter and Power Co.; residence, 224 Carlisle Ave., York, Pa.	Mar. 20, 1895
SHUSTER, JOHN WESLEY	Instructor in Electrical Engineering, University of Wisconsin; residence, 609 Lake Street, Madison, Wis.	Jan. 3, 1902
SIMPSON, ALEXANDER B.	Electrical Engineer, 54 Maiden Lane, N. Y. City.	May 21, 1891
SIMPSON, ERNEST LEE	Electrical Engineer, The Mexican Gas and Electric Light Co., Santa Clara No. 7, Mexico City, Mex.	Sept. 27, 1901
SIMPSON, J. MANLEY	Assistant to General Superintendent, American Grass Twine Co., P. O. Box 2513, St. Paul, Minn.	Jan. 25, 1899
SISE, CHARLES F.	President, Bell Telephone Co., of Canada, P. O. Box 2262, Montreal, Canada.	June 8, 1887
SKINNER, CHARLES EDWARD	Electrical Engineer, Westinghouse E. & M. Co.; residence, 424 Franklin Ave., Pittsburg, Pa.	Apr. 26, 1899
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph Cable Co., New York City; residence, 183 N. 19th St., East Orange, N. J.	Sept. 25, 1895
SLADE, ARTHUR J., *Ph.D.*	Mechanical Engineer, Grand Central Station, New York City; residence, Pelham Manor, N. Y.	Sept. 19, 1894

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Name.	Address.	Date of Election.
SLATER, FREDERICK R.	Asst. Electrical Engineer, Manhattan Railway, 32 Park Place; residence, 201 West 73d St., New York City.	Oct. 17, 1894
SLICHTER, WALTER I.	Electrical Engineer, General Electric Co.; residence, 234 Union St., Schenectady, N. Y.	April 25, 1900
SLOAN, JAMES RICHARD	Electrical Engineer, The Pullman Co., P. R. R. Depot, Jersey City, N. J.; residence, 607 West 61st Place, Chicago, Ill.	Feb. 28, 1902
SMITH, FRANK WARREN	Superintendent, The Cutler Hammer Mfg. Co., 20 Charles St., Westfield, N. J.	Sept. 27, 1901
SMITH, FREDERICK B.	Electrical Specialties, 170 Summer St., Boston, Mass.	July 26, 1900
SMITH, IRVING B.	Partner, The Wirt Electric Co., 180 Broadway, New York City.	May 15, 1900
SMITH, IRVING WILLIAMS	Electrician Bishop Gutta Percha Co., 420 E. 25th St ; residence, 5 W. 90th St., New York.	Jan. 9, 1901
SMITH, J. BRODIE	General Manager, Manchester Electric Co. and Manchester Street Railway, 142 Merrimack St., Manchester, N. H.	Mar. 21, 1894
SMITH, OBERLIN	President and Mechanical Engineer, Ferracute Machine Co., Lochwold, Bridgeton, N. J.	May 19, 1891
SMITH, T. JARRARD	Manufacturers and Inventors' Electric Co., 96 Fulton St., Tel. 838 John, New York City; residence, Roselle, N. J.	April 19, 1892
SMITH, SAMUEL JAMES	Salesman and Installing Engineer, Crocker-Wheeler Co , 40 So. Tryon St., Charlotte, N. C.	Oct. 24, 1900
SMITH, SAMUEL NEWTON	Manager of Sales, Submerged Electric Motor Co., Menomonie, Wis.; residence, 725 Temple Court, Minneapolis, Minn.	Oct. 25, 1901
SMITH, SAMUEL WILLIAM	General Storekeeper and Purchasing Agent, Lachine Rapids Hydraulic and Land Co., Ltd., 160 McCord St.; residence, 172 Versailles St., Montreal, Canada.	Sept. 27, 1901
SMITH, WALTER EUGENE	Electrician, The United States Navy Department, Midvale Steel Works; residence, 2126 Ontario St., Philadelphia, Pa.	Feb 28, 1900
SMITH, WALTER F.	General Manager, United Gas Improvement Co.; residence, 2010 Ontario St., Philadelphia, Pa.	July 26, 1900
SMITH, WM. LINCOLN	Consulting Electrical and Illuminating Engineer; residence, 360 Marlborough St., Boston, Mass.	July 18, 1899
SMITH, WILLIAM NELSON	Electrical Engineer, Westinghouse, Church, Kerr & Co., 26 Cortlandt St., New York City; residence, 62 Morris St., Yonkers, N. Y.	Mar. 28, 1902

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Name.	Address.	Date of Election.
SMITH, WM. STUART	U. S. N., 2538 Dwight Way, Berkeley, Cal.	July 26, 1901
SNYDER, NATHANIEL MARION,	County Surveyor for Scotts Bluff Co., Gering, Nebraska.	Nov. 23, 1900
SOMELLERA, GABRIEL F.	Partner, Salcedo & Co., Apartado 115, Mexico City, Mex.	April 25, 1900
SOREN, TOWNSEND HODGES	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Nov. 22, 1901
SOWERS, DAVID W.	Sup't Buffalo Branch, New York Electric Vehicle Transportation Co., 240 W. Utica, St., residence, 67 W. North St., Buffalo N. Y.	July 18, 1899
SPELLMIRE, WALTER B.	District Engineer, Bullock Electric Mfg. Co., 220 Broadway, New York City.	May 21, 1901
SPENCER, CHAS. J.	Electrical Engineer, with N. Y. C. & H. R. R. R. Engineering Dept., Room 512 Grand Central Station, New York City.	May 21, 1901
SPENCER, PAUL	Inspector of Electric Plants, United Gas Improvement Co., Broad and Arch Sts., Philadelphia, Pa.	Nov. 30, 1897
SPENCER, THEODORE	With Bell Telephone Co., N. E. Cor. 11th and Filbert Sts., Philadelphia, Pa.	Mar. 21, 1893
SPERLING, R. H.	Assistant Engineer, British Columbia Electric Railway Co., Ltd., Victoria, B. C.	Nov. 23, 1898
SPIESE, F. P.	Secretary, Treasurer and Manager the Edison Electric Illuminating Co., Tamaqua, Penn.	July 26, 1900
SPOEHRER, HERMANN	Laboratorian, in charge of Test Room, Equipment Department, New York Navy Yard; residence, 472 Second Ave., New York City.	Sept. 27, 1901
SQUIER, GEORGE O. CAPT.,	*Ph.D.* U. S. Signal Corps, c/o Chief Signal Officer, Div. of the Pacific, Manila, P. I.	May 19, 1891
STAHL, TH.	Mining Engineer for Messrs. Schneider & Co., Grenoble, France.	Nov. 15, 1892
STAKES, D. FRANKLIN	Electrical Engineer; residence, 5372 Morris St., Germantown, Philadelphia, Pa.	Jan. 20, 1897
STANTON, CHAS. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 134 S. 3d St., Philadelphia, Pa.	Mar. 20, 1895
STEELE, WALTER D.	Electrical Engineer, with Westinghouse, Church, Kerr & Co., 26 Cortlandt St.	April 25, 1900
STERN, PHILIP KOSSUTH	Practicing Electrical and Mechanical Engineering, 130 Fulton St., N. Y.	Nov. 23, 1900
STEVENS, CABOT	Electrical Engineer, Brooklyn Edison Electric Illuminating Co., 360 Pearl St.; residence, 11 St. James Place, Brooklyn, N. Y.	June 28, 1901

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Name.	Address.	Date of Election.
STEWART, JOHN BRUCE	Superintendent, Electric Plant, Virginia Hot Springs Co., Hot Springs, Va.	Aug. 23, 1899
STINE, WILBUR M.	Professor of Engineering, Swarthmore College, Swarthmore, Pa.	May 15, 1894
STITZER, ARTHUR BOWERS,	Draughtsman, Union Traction Co.; residence, 1909 N. Camac St., Philadelphia, Pa.	Oct. 24, 1900
STOCKBRIDGE, GEO. H. [Life Member.]	Patent Attorney, 120 Broadway; residence, 2514 11th Ave., near 187th St., New York City.	May 24, 1887
STONE, CHARLES A.	With Firm of Stone & Webster, 93 Federal St., Boston, Mass.	May 19, 1891
STONE, JOSEPH P.	Officina de Traccioux y Talleres, Ferro Carril del Sud, Estacion Sola; residence, Avenida Montes de Oca 415, Buenos Aires.	Dec. 18, 1895
STORER, NORMAN W.	Electrical Engineer, Westinghouse Electric and Mfg. Co., residence, 6109 Howe St., E. E. Pittsburg, Pa.	Dec. 18, 1895
STOUT, JOSEPH SUYDAM, JR.,	Inspector, The New York Edison Co.; 55 Duane St., residence, 35 East 67th St., New York City.	Nov. 22, 1899
STRAUS, THEODORE E.	Electrical Engineer, 13 W. Pratt St., residence, 1213 Linden Avenue, Baltimore, Md.	Nov. 18, 1896
STRAUSS, HERMAN A.	Consulting Electrical Engineer, Park Row Building (Tel. 6555, Cortlandt), residence, 141 W. 110th St., New York City.	Oct. 17, 1894
STRONG, JAMES REMSEN	President, The Tucker Electric Construction Co., 35 South William St., N. Y.; residence, Short Hills, N. J.	Mar. 22, 1901
STUART, HARVE R.	Electrical Engineer, with W. E. & M. Co.; residence, 524 Wallace Ave., Wilkinsburg, Pa.	Jan. 25, 1901
STURDEVANT, CHAS. RALPH	With E. P. Roberts & Co., Consulting Engineers, 603 Electric Building, Cleveland, Ohio.	May 16, 1899
STURTEVANT, CHARLES L.	Patent Attorney, Atlantic Building, Washington, D. C.	Dec. 20, 1893
STUTZ, CHAS. C.	Assistant Chief Engineer, Pittsburg Plate Glass Co., Carnegie Building, Pittsburg, Pa.	Mar. 28, 1900
SUDLOW, HARRY	16 Charlotte St., Charleston, S. C.	Sept. 27, 1901
SULLIVAN, WILLIAM VAN AMBERG, JR.	Consulting and Contracting Mechanical and Electrical Engineer, Room 120, Washington Building; residence, 618 Terry Ave., Seattle, Wash.	Jan. 24, 1902
SUMMERS, LELAND L.	Electrical Engineer, 441 The Rookery, Chicago, Ill.	Feb. 16, 1892
SWENSON, BERNARD VICTOR	Assistant Professor of Electrical Engineering, University of Wisconsin, 404 W. Mifflin St., Madison, Wis.	Feb. 27, 1895

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Name.	Address.	Date of Election.
SWEET, HENRY N.	Second Vice-President, Duncan Hall, 1151 Chapel St., New Haven, Conn.	May 20, 1890
SWEETLAND, RALPH	Electrical Inspector, New England Insurance Exchange, 55 Kilby St., Boston; residence, Natick, Mass.	Oct. 25, 1901
SWOPE, GERARD	Manager, Western Electric Co., 810 Spruce St., St. Louis, Mo.	Apr. 26, 1899
SYKES, HENRY H.	Gen. Supt., Southern New England Telegraph Co., New Haven, Conn.	Oct. 18, 1893
SZUK, GEZA	Chief Engineer, Ganz & Co: residence, Csalogany utcza 52 Budapest II, Hungary.	Jan. 3, 1902
TACHIHARA, JIN	Electrical Engineer, Mining Dep't, Mitsu Bishi Co., Tokyo, Japan.	Jan. 26, 1898
TAIT, FRANK M.	Superintendent, The Somerset Lighting Co., Somerville, N. J.	Sept. 19, 1894
TANNATT, EBEN TAPPAN	Managing Civil and Electrical Engineer, The Oahu College Trustees; residence, 1313 Wilder Ave., Honolulu, H. Ty.	Nov. 22, 1901
TAPLEY, WALTER H.	Electrician in Government Printing Office, care of Public Printer, Washington, D. C.	Oct. 25, 1892
TAYLOR, ALBERT	Manager New York Office, Electric Storage Battery Co., 100 Broadway, New York City.	May 21, 1901
TAYLOR, FRANK H.	Westinghouse Electric & Mfg. Co.; residence, 7422 Penn Ave., Pittsburg, Pa.	Jan. 8, 1902
TAYLOR, IRVING A.	McCord and Seminary Sts., Montreal, P. Q.	May 17, 1898
TAYLOR, JEREMY F.	[Address unknown.]	Dec. 27, 1899
TEMPLE, WILLIAM CHASE	Consulting Engineer, Bank of Commerce Bldg., residence, 1090 Shady Ave., Pittsburg, Pa.	May 3, 1887
TERRY, ALBERT SLOCOMB	Treas. and Manager, The Sunbeam Incandescent Lamp Co., 463 West St.; residence, 59 Morningside Ave., New York City.	Jan. 24, 1902
TERVET, ROBERT	Technical Engineer, Western Electric Co., North Woolwich, London; residence, 4 Christie Road, South Hackney, London, N. E., England.	Sept. 27, 1901
TESLA, NIKOLA	Electrical Engineer and Inventor, 46 E. Houston St., New York City.	June 5, 1888
THAYER, GEORGE LANGSTAFF, *M. E.*,	Consulting Electrical Engineer, Oregon Short Line R. R. Co., Geneva, Ind.	Aug. 5, 1896
THOMAS, ALFRED CLARENCE	Engineer, The New York & New Jersey Telephone Co, 81 Willoughby St.; residence, 131 De Kalb Ave., Brooklyn, N. Y.	Feb. 28, 1902

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Name.	Address.	Date of Election
THOMAS, JOHN WILLIAMS	Construction Engineer, Electric Storage Battery Co., Hokendauqua, Pa.	Mar. 22, 1901
THOMAS, PERCY HOLBROOK,	Electrical Engineering Department, Westinghouse E. & M. Company, Pittsburg, Pa.	Oct. 24, 1900
THOMAS, ROBERT MCKEAN,	*E. E.* Member of the firm of Thomas & Betts, 141 Broadway; residence, 135 Madison Ave., New York City.	April 22, 1896
THOMPSON, ALFRED J.	Crocker, Wheeler Co., Ampere, N. J.	Jan. 25, 1899
THOMPSON, ERMINE JOHN	In Testing Rooms Stanley Electric M'f'g. Co., 166 Union St., Pittsfield, Mass.	Jan. 25, 1901
THOMPSON, JOHN WEST	Director, Dept. de Electricidad, Cia Industrial de Guadalajara, Box 174, Guadalajara, Mexico.	Sept. 28, 1898
THOMPSON, MILTON T.	Constructing Engineer, Mexican General Electric Co., Apartado 403, Mexico City, Mexico.	Jan. 24, 1900
THOMPSON, SILVANUS P.	Morland, Chislett Road West Hampstead, London, N. W., England.	Oct. 27, 1897
THOMPSON, THOS. PERRIN	Consulting Engineer, Neff & Thompson, Architects and Engineers, Withers Building, Norfolk, Va.	Jan. 25, 1899
THOMPSON, WARREN RAY,	Assistant in Electrical Engineering Department, J. G. White & Company, 22a College Hill, Cannon St., London, England	Oct. 24, 1900
THOMSON, CLARENCE	Examiner, The Patent Office, Ottawa, Canada.	May 15, 1900
THOMSON, GEO. ANDROS	Special Agent, The Adams-Bagnall Electric Co., 136 Liberty St., New York; residence, Somerville, N. J.	Mar. 22, 1901
THORDARSON, CHESTER H.	Manufacturing Electrican, 128 LaSalle Ave.; residence, 6415 Lexington Ave., Chicago, Ill.	Dec. 18, 1895
THORNTON, KENNETH BUCHANAN	Superintendent Line Department, The Royal Electric Co., residence, 840 Dorchester St. Montreal, P. Q.	Apr. 26, 1901
THURBER, HOWARD F.	General Superintendent, New York Telephone Co., 18 Cortlandt Street, New York City; residence, 49 Sidney Place, Brooklyn, N. Y.	Mar. 25, 1896
TIDD, GEO. N.	Electrical Engineer and Manager, Beacon Light Co., Chester, Pa.	July 26, 1900
TINGLEY, E. M.	Westinghouse Elec. & Mfg. Co.; residence, 431 Shady Ave., Pittsburg, Pa.	July 12, 1900

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Name.	Address.	Date of Election.
TOBEY, HARRY WILLLARD	Member Engineering Department, Stanley Electric Mfg. Co.; residence, 36 Oxford St., Pittsfield, Mass.	Sept. 27, 1901
TOERRING, C. J.	C. J. Toerring Co., 1035 Ridge Ave., Philadelphia, Pa.	April 18, 1894
TOLMAN, CLARENCE M.	Electrical Engineer, Seattle, Washington,	April 27, 1898
TORCHIO, PHILIPPO	Engineering Dep't, The New York Edison Co., 53 Duane Street, New York City.	June 27, 1895
TOURET, MAXIME EUGENE JEAN	Electrical Consulting Engineer, 7 Rue Meyerbeer, Paris, France.	Jan. 24, 1902
TOWER, GEORGE A.	V. P. Tower-Binford Electric and Mfg. Co., 7 South Seventh St.; residence, 102 West Grace St., Richmond, Va.	May 15, 1894
TOWN, FREDERICK E.	Civil and Electrical Engineer, Supervising Architect's Office, Treasury Department, Washington, D. C.	May 15, 1900
TOWNLEY, CALVERT	General Agent, Westinghouse Electric and M'f'g. Co., 120 Broadway, New York City.	Feb. 28, 1901
TOWNSEND, HENRY C.	Attorney and Expert in Electrical Cases, 141 Broadway; residence, 354 W. 123d St., New York City.	July 10, 1888
TOWNSEND, FITZHUGH	Electrical Engineer, 116th Street and Amsterdam Ave.; residence, Union Club, Fifth Ave. and 21st St., New York City.	Jan. 20, 1894
TREADWELL, AUGUSTUS, JR.	*E. E.*, 100 Broadway, New York City; residence, 488 3d St., Brooklyn, N. Y.	Feb. 21, 1894
TREAT, ROBERT BELDEN	Electrical Engineer, Crocker-Wheeler Co., Ampere, N. J.; residence, 43 South 10th St., Newark, N. J.	Jan. 3, 1902
TRIPIER, HENRI	Technical Engineer of the Societe Francaise d'Incandescence par le gaz (Systeme Auer.); residence, 110 Bd. Malesherbes, Paris, France.	Sept. 28, 1898
TROTT, A. H. HARDY [Life Member.]	Beer, near Axminster, Devonshire, Eng.	Jan. 20, 1891
TRUDEAU, J. A. G.	329 Kent Street, Ottawa, Canada.	May 15, 1900
TRUESDELL, ARTHUR E.	50 Brenton Terrace, Pittsfield, Mass.	Feb. 15, 1899
TURNBULL, WALLACE RUPERT.	Electrical Engineer, St. Johns, N. B., Canada.	May 17, 1898
TYNDALL, CHARLES H., *Ph. D.*	Minister Reformed Church, 137 South Sixth Ave., Mt. Vernon, N. Y.	Sept. 27, 1901
TYNG, FRANCIS E.	Manager, Eastern Engineering Co., 164 W. 27th St., New York; residence, Cranford, N.J.	Dec. 28, 1898

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Name.	Address.	Date of Election.
VAIL, THEO. N.	26 Cortlandt St., New York City.	April 15, 1884
VAN BUREN, GURDON C.	Electrical Expert, with Federal Instrument Co., 62 South Hawk St., Albany, N. Y.	Oct. 25, 1892
VAN DYCK, WILLIAM VAN BERGIN	Electrical Engineer and Contractor; residence, 439 Manhattan Ave., New York City.	Nov. 22, 1901
VANDEGRIFT, JAMES A.	Treasurer and Manager, The Colorado Lamp Co., 2051 California St., Denver, Col.	Nov. 24, 1891
VANDERVEEN, ANTHONY R.	Machinist, The South India Railway Co., Holland Road, Negapatam, India.	Jan. 9, 1901
VAN DEVENTER, CHRISTOPHER	Stanley Electric Mfg. Co., 71 Broadway, New York City.	Feb. 17, 1897
VANKIRK, EDWARD POWER	Electrical Engineer, Westinghouse Air Brake Co., Wilmerding, Pa.	Jan. 3, 1902
VAN VLEET, ROY MITCHELL	Student, Westinghouse Electric and M'f'g Co., Edgewood Park, Pa., residence, Port Huron, Mich.	Mar. 22, 1901
VAN WYCK, PHILIP V. R., JR.	New York Telephone Co., 15 Dey St.; residence, Plainfield, N. J.	April 21, 1891
VARNEY, FRANK H.	Electrician, San Francisco Gas and Electric Co., 2912 Mission St., San Francisco, Cala.	July 26, 1900
VARNEY, WILLIAM WESLEY	City Commissioner of Baltimore, office, City Hall; residence 712 N. Carey St., Baltimore, Md.	Nov. 21, 1894
VENABLE, CAPT. WM. MAYO	The National Contracting Co., 713 Hennen Bldg., New Orleans, La.	Nov 30, 1897
VIEHE, J. S.	Westinghouse Electric and Mfg. Co., 103 Circuit Court, Roxbury, Boston, Mass.	May 15, 1900
VINTEN, ERNEST STILES	Foreman Knob. Dept. Sargent Co.; residence, 89 Pearl St., New Haven, Conn.	April 27, 1898
VOIT, DR. ERNST	Professor of Electricity, Technical University, Schwanthalerstrasse, Munchen, Germany.	Mar. 21, 1894
VREELAND, FREDERICK K.	Box 1877, New York City.	Oct. 26, 1898
DE WAAL, WM. H.	Engineer, Accumulator Mfg. Co., Apartado 626, Mexico City, Mexico.	April 25, 1900
WADDELL, CHARLES EDWARD	Electrician in charge Electrical Department, Biltmore Estate, Biltmore, North Carolina.	April 25, 1902
WAGNER, HERBERT A.	Consulting Engineer, 415 Locust St., St. Louis, Mo., and Times Building, New York City.	Sept. 28, 1898
WAGONER, PHILIP DAKIN	Commercial Department, General Electric Co., Box 728 Schenectady, N. Y.	Feb. 28, 1902

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Name.	Address.	Date of Election.
WALKEM, GEORGE ALEXANDER	Electrical and Mechanical Engineer, P. O. Box 595, Vancouver, B. C.	Nov. 23, 1900
WALKER, FRANK WILKES	Mechanical and Electrical Engineer, New York Telephone Co.; residence, 26 Summerhill Ave., Montreal, P. Q.	May 21, 1901
WALKER, MILES	Electrical Engineer, The British Westinghouse Electric and Mfg. Co., Ltd.; residence, 413 Pitt St., Pittsburg, Pa.	Sept. 27, 1901
WALLACE, CHAS. F.	Engineer, Stone and Webster, 93 Federal St., Boston; residence, Wellesley Hills, Mass.	Nov. 18, 1896
WALLAU, HERMAN L.	Assistant Electrician, Cleveland Elec. Ill. Co., 711 The Cuyahoga, Cleveland, Ohio.	May 15, 1900
WALLER, CHAS. WAITE	Sales Agent, General Electric Co., Claus Spreckels B'ld'g, San Francisco, Cal.	Aug. 23, 1899
WALMSLEY, WALTER NEWBOLD	1002 Harrison Bldg., Philadelphia, Pa.	Oct. 24, 1900
WARNER, CHAS. H.	Consulting Electrical Engineer, 764 Rock St., Fall River, Mass.	Dec. 20, 1893
WARREN, ALDRED KENNEDY	Assistant Engineer of Line and Equipment, Brooklyn Heights R.R. Co., 2075 Broadway, Brooklyn; residence, 114 E. 17th St., New York City.	Nov. 20, 1895
WARREN, HENRY ELLIS	Assistant Engineer, The Lombard-Governor Co., 36 Whittier St. Boston; residence, Newton Centre, Mass.	Jan. 24, 1902
WASON, CHAS. W.	President and Purchasing Agent, Cleveland, Painesville and Eastern R. R., Purchasing Agent, Akron, Bedford and Cleveland R. R., 616 Garfield Bldg., Cleveland, O.	May 19, 1891
WATERMAN, MARCUS B.	Assistant Electrician, Consolidated Telegraph and Electrical Subway Co., 55 Duane St., New York City; residence, 177 Lefferts Place, Brooklyn, N. Y.	Feb. 15, 1896
WATERS, EDWARD G.	General Electric Co., 44 Broad St., New York City.	Mar. 18, 1890
WEBB, HENRY STORRS [Life Member.]	International Correspondence Schools; residence, 1416 Monsey Ave., Scranton, Pa.	Nov. 20, 1895
WEBB, HOWARD SCOTT	Professor of Electrical Engineering, University of Maine, Orono, Maine.	Oct. 24, 1900
WEBSTER, EDWIN S	Firm of Stone & Webster, 93 Federal St., Boston, Mass.	April 21, 1891

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Name.	Address.	Date of Election.
WEBSTER, WALTER COATES.	Assistant to 2d Vice-President Westinghouse Electric & Mfg. Co., 120 Broadway, New York City.	Jan. 3, 1902
WELLES, FRANCIS R.	Manufacturer, 46 Avenue de Breteuil, Paris, France.	Sept. 6, 1887
WELLMAN, HAROLD ROBINSON	Electrical Engineer, Motor Department, General Incandescent Arc Light Co., 572 First Ave; residence, 3 Beech Terrace, New York City.	April 25, 1902
WELLS, GEORGE EUGENE	Consulting Electrical Engineer, Ruebel & Wells, 1112 Chemical Building, St. Louis, Mo.	Sept. 27, 1901
WELLS, WALTER FARRINGTON	Supt. 3rd Dist., The New York Edison Co., 55 Duane St.; residence, 69 East 92d St., New York, N. Y.	Apr. 26, 1899
WENGER, EDGAR I.	Graduate in Electrical Engineering, McGill University; residence, Ayton, Ontario.	May 21, 1901
WEST, JULIUS HENRIK	Engineer, Handjery St., 58 Friedenau, Berlin, Germany.	Sept. 20, 1893
WESTON, SYDNEY F.	Marine Engine and Machine Co., 1123 Broadway, Room 1116; residence, 22 Gramercy Park, New York City.	July 12, 1900
WEYMOUTH, THOMAS ROTE	Electrical Engineer, International Hydraulic Co., 40 Wall St.; residence, 80 Washington Square E., New York City.	Nov. 22, 1901
WHEILDON, LOUIS B.	Contractor and Expert, 1027 Exchange Building, Boston, Mass.	Oct. 24, 1900
WHITAKER, S. EDGAR	Sec'y and Treas., Massachusetts Engineering Co., Street Railways, Room 1, 43 Milk St., Boston, Mass.; residence, 135 Shurtleff St., Chelsea, Mass.	Aug. 5, 1896
WHITE, CHAS. G.	Public Schools Sup't, and Instructor in Physics and Chemistry, Lake Linden, Mich.	Sept. 23, 1896
WHITEHEAD, JOHN B., JR.,	Associate in Applied Electricity, Johns-Hopkins University, Baltimore, Md.	Oct. 24, 1900
WHITE, FRANCIS JOSEPH	Student, Columbia University; residence, 53 St. John's Place, Brooklyn, N. Y.	April 25, 1902
WHITE, LINDEN G.	Superintendent Electrical Department The Columbus Edison Co, 3d and Gay Sts., Columbus, Ohio.	Mar. 28, 1902
WHITESIDE, WALTER HUNTER	Manager, Westinghouse E. & M. Co, East Pittsburg; residence, 6843 Thomas Boulevard, Pittsbhrg, Pa.	Jan. 24, 1902

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Name.	Address.	Date of Election.
WHITING, ALLEN H.	Assistant Engineer, Riker Electric Vehicle Co., Elizabethport, N. J. residence, 320 Lexington Ave., New York City.	Nov. 18, 1896
WHITING, S. E.	Assistant in Electrical Dep't., Harvard University; residence, 11 Ware St., Cambridge, Mass.	May 16, 1899
WHITMORE, W. G.	Electrical Engineer, General Electric Co., Edison Building, Box 3067, New York City.	Mar. 18, 1890
WHITNEY, CLINTON EUGENE	Electrical and Mechanical Engineer, 553 South 6th Ave., Mt. Vernon, N. Y.	Nov. 22, 1899
WHITNEY, HENRY M. [Life Member.]	95 Milk St., Boston, Mass.	July 12, 1887
WHITNEY WILLIS R.	Asst. Prof. Theoretical Chemistry, Massachusetts Institute Technology, in charge of Electro-Chemical Research Laboratory, General Electric Co., Schenectady, N. Y.	May 21, 1901
WHITTED, THOS. BYRD	District Engineer, The General Electric Co., Denver, Col.	Mar. 22, 1899
WHITTEMORE, GEORGE W.	Engineer Bell Telephone Co., 24 W. Seneca St, Buffalo, N. Y.	Jan. 3, 1902
WIDDICOMBE, ROBERT A.	Engineer, Western Electric Co.: residence, 1651 Roscoe St., Chicago, Ill.	Apr. 26, 1899
WIEDERHOLD, OSCAR	Supt. Natural Light Supply Co., 90 Orange St., residence, 14 Grace St., Bloomfield, N. J.	Aug. 13, 1897
WIESELGREEN, CARL EMIL	Allgemeine Electricitats Gesellschaft, Brunnenstrasse, Berlin, Ger.	Oct 24, 1900
WIGHTMAN, MERLE J.	Electrical Engineer, 150 Nassau St., New York City.	Mar. 5, 1889
WILDER, HENRY WINDSOR	Electrical Engineer, Hudson River Telephone Co., Albany, N. Y.	Sept. 27, 1901
WILER, CARL	Electrical Engineer, Western Electric Co., Chicago, Ill.	Sept. 27, 1901
WILEY, GEO. FOURIE	Manager, Standard Underground Cable Co., 56 Liberty St., New York, residence, Arlington, N. J.	Feb. 28, 1900
WILEY, WM. H.	Scientific Expert, 43 E. 19th St., New York City.	Feb. 7, 1888
WILKES, C. M.,	Engineer, D. H. Burnham & Co., 1142 The Rookery, Chicago, Ill.	Nov. 22, 1899
WILKINSON, JAMES	Chief Engineer Birmingham Railway, Light and Power Co.; residence, 1212 North 17th St., Birmingham, Ala.	Feb. 28, 1902
WILLIAMS, ARTHUR	General Inspector, The New York Edison Co., of New York; residence, 261 Linden Boulevard, Brooklyn, N. Y.	June 23, 1897

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Name.	Address.	Date of Election.
WILLIAMS, CHARLES JR.	Electrician, 1 Arlington Street, East Somerville, Mass.	April 15, 1884
WILLIAMS, GEO. HENRY	Lulworth, St. Andrews Park, Bristol, England.	Oct. 27, 1897
WILLIAMS, WILLIAM HENRY	Professor of Electrical Engineering, Montana State College, Bozeman, Mont.	Sept. 28, 1898
WILSON, HENRY CLINTON	Chief Engineer, Chapman Double Ball Bearing Co., 49 Wall St., New York City.	Sept. 27, 1901
WILSON, ROBERT LEE	Constructing Engineer, Westinghouse Electric and Mfg. Co.; residence, The "Gainsborough," 5th Ave. & 120th St., New York City.	June 28, 1901
WILSON, ROBERT M.	Royal Electric Co.; residence, 23 Seymour Ave., Montreal, P. Q.	Jan. 25, 1899
WINAND, PAUL A. N.	Engineer and Supt., Schleicher, Schumm & Co., 3200 Arch St., Philadelphia, Pa.	June 20, 1894
WINCHESTER, SAMUEL B.	Superintendent Electrical Department, of the Holyoke Water Power Co., 5 Laurel St., Holyoke, Mass.	May 15, 1894
WINFIELD, JAMES H.	General Manager, Nova Scotia Telephone, Ltd., Box 343, Halifax, N. S.	May 17, 1898
WINSLOW, I. E.	The General Traction Company, Ltd., 35 Parliament Street, Westminster, London, Eng.	Nov. 12, 1889
WINTNER, LOUIS	Engineer Switchboard Department, General Incandescent Arc Light Co., 572 First Ave., New York City.	May 21, 1901
WINTRINGHAM, J. P.	Theorist, 36 Pine St., New York City, and 153 Henry St., Brooklyn, N.Y.	May 7, 1889
WIRT, HERBERT C.	Engineer, Supply Department, General Electric Co., Schenectady, N. Y.	June 26, 1891
WISE, JOHN SHREEVE, JR.,	Assistant Supt., Auburn Light, Heat and Power Co., Auburn, N. Y.; residence, 2023 Mt. Vernon St., Philadelphia, Pa.	Feb. 15, 1896
WOLF, LEE H.	Contracting and Engineering, Honolulu, H. I.	Oct. 24, 1900
WOLFE, JOSEPH THOMAS	General Engineer and Sales Agent, Noyes Bros., 15 Queen St., Melbourne, Victoria.	June 28, 1901
WOLFF, FRANK A. JR.,	Professor of Physics and Electrical Engineering, Corcoran Scientific School, Columbian University, and in office U. S. Standard Weights and Measures, Washington, D. C.	Dec. 27, 1899
WOODBRIDGE, J. E.	Railway Engineering Department, General Electric Co., Schenectady, N. Y.	Oct. 26, 1898

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Name.	Address.	Date of Election.
WOODBURY, DANIEL CORYTON	Student, Stevens Institute of Technology; residence, 934 Bloomfield St., Hoboken, N. J.	Apr. 25, 1902
WOODFIELD, SYDNEY	Assistant Engineer Electrical Power Distribution Co., York House, Norfolk St.; residence, 24 Sinclair Gardens, Kensington, London, Eng.	Feb. 28, 1902
WOODWARD, FREDERICK SEARLE	Residence, 265 Prospect Pl., Brooklyn, N. Y.	June 28, 1901
WOODWORTH, GEO. K	Assistant Examiner, U. S. Patent Office; residence, 1424 S St., N. W., Washington, D. C.	Feb. 17, 1897
WOODWORTH, LEON BYRON	Electrical Engineer, New Heriot Gold Mining Co., Johannesburg, Transvaal.	Nov. 23, 1900
WOODWORTH, PHILIP BELL	Professor of Electrical Engineering, Lewis Institute, Chicago; residence, 5808 Ohio St., Austin, Ill.	July 12, 1900
WOOLF, ALBERT E.	Electrician and Inventor, The Electrozone Co , 415 Lexington Ave., New York City.	Sept. 16, 1890
WORSWICK, A. E.	Vice-President and Resident Engineer F. C. D., 3rd Calla de las Artes, Mexico City.	Sept. 20, 1893
WRAY, J. GLEN	Superintendent of Maintenance, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	Sept. 20, 1893
YARNALL, VERNON H.	Eastern Manager McRoy Clay Works, 302 Broadway, Room 907, New York City.	May 16, 1893
YOUNG, CHARLES I.	Electrical Engineer, Westinghouse Elec. & Mfg. Co., 120 Broadway, New York City.	June 27, 1895
YAMAZAKI, SHIRO	Student of Electrical Engineering, Cornell University, 408 University Ave., Ithaca, N. Y.; residence, Tokyo, Japan.	Jan. 24, 1902
YORKE, GEORGE MARSHALL	Assistant Electrician American Telephone and Tel. Co.; 15 Dey St., residence, 44 Irving Place, New York City.	Apr. 25, 1902
YSLAS, CARLOS	Civil and Electrical Engineer, Martinez del Villar, Yslas & Co., Calle Principal, No. 8.	Nov. 18, 1896
ZABEL, MAX W.	Patent Solicitor, with Chas. A. Brown, Cragg & Belfield. 1450 Manadnock, residence, 454 North Ave., Chicago, Ill.	Jan. 24, 1900
ZAHM, A. WILFORD	Electrical Engineer and Supt., Manhattan Light Heat and Power Co., Manhattan Building, St. Paul, Minn.	Nov. 23, 1898

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Name.	Address.	Date of Election.
ZALINSKI, EDMUND L.	Captain of Artillery, U. S. A., (retired), The Century, 7 West 43d St., New York City.	May 17, 1887
ZANI, ARNALDO P.	Electrical Engineer, Thomson-Houston Co., Piazza Cartello 5, Milano, Italy.	July 12, 1900
ZAPATA, J. M.	Constructing Engineer, Compandia Carris de Ferro de Lisbon, Lisbon, Portugal.	Feb. 28, 1900
ZURFLUH, WILLIAM NICHOLAS	Superintendent Home Lighting Power & Heating Co., Room 11, Arcade Building, Springfield, Ohio.	Jan. 3, 1902
ZWIETUSCH, EDWARD OTTO (5)	Electrical Engineer, Telephon Apparat Fabrik Petsch, Zwietusch & Co., Salzufer 7, Charlottenburg, Germany.	Nov. 22, 1961

Associate Members, - - - - 1141

OFFICIAL STENOGRAPHER

RYAN, RICHARD W., 150 Nassau Street, Telephone, 3448 John. Residence, 521 W. 150th St., New York City.

SUMMARY.

Honorary Members, - - - - - - - - -	2
Members, - - - - - - - - - - -	403
Associate Members, - - - - - - - -	1141
Total - - - -	1546

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Little Rock.—Keller, C. A.

CALIFORNIA.

Auburn.—Robinson, A. L.

Bakersfield.—Bowie, A. J. Jr.

Berkeley.
Cory, Prof. C. L.
Le Conte, Joseph N.
Lynn, W. A.
Mortimer, Jas. D.
Smith, W. Stuart. 5

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Haywards.—Clement, L. M.

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Boyd, J. D.
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Baldwin, G. P.
Cooke, G. A.
Copeland, C. A. 3

Marysville.—Theberath, T. E.

Nevada City.—Hancock, L. M.

Oakland.
Gaytes, Herbert, 395 Vernon St.
Holberton, G. C., 13th & Clay Sts. 2

Oroville, Montague, R. L.

Pasadena.—Foote, T. H.

Riverside.—Henderson, H. B.

Sacramento.
Crowell, Robinson
Hutton, C. W. 2

San Francisco.
Allen, W. H., 331 Pine St.
Barbour, Fred F., Claus Spreckels Bg.
Broili, Frank, 154 Hickory Ave.
Bunker, A. C., 238 Crocker B'ld'g.
Daggett, R. B., 42 Nevada Block.
Foster, S. L., Market & Valencia.
Glass, Louis, Telephone Bldg.
Greenwood, F. A., 409 Market St.
Hanscom, W. W., 612 O'Farrell St.
Henry, G. J., Jr., 127 Main St.
Hewitt, Wm. R., 9 Brenham Place
Hitzeroth, L. D., 18 Second St.
Hunt, A. M., 331 Pine St.
Knight, P. H.
Lee, F. V. T., 33 New Montgomery
Lighthipe, Jas. A., Claus Spreckels Bg.
Low, George P., 320 California St.
Martin, John, 33 New Montgomery
Masson, R. S., 321 Market St.
Meredith, Wynn, 331 Pine St.
Molera, E. J. 606 Clay St.
Napthaly, S. L., 229 Stephenson St.
Poole, C. O., Crocker B'ld'g.
Ridley, A. E. B., 598 Parrott B'ld'g
Russell, H. A., 302 Laurel St.
Smith, F. E., 183 Jessie St.
Varney, F. H., 2912 Mission St.
Waller, C. W., Claus Spreckels Bldg. 26

San Rafael.—Remschel, C. W. A.

Stanford University.—Baum, F. G.

Stockton.—Adams, F. P.

COLORADO.

Aspen.—Doolittle, Clarence E.

Canon City.—Wilcox, N. T.

Denver.
Hogan, C. W.
Searing, L., 924 Washington Ave.
Sethman, G. H., 2305 Boulevard F.
Stearns, J. W. Mountain Elec. Co.
Vandegrift, J. A., 2051 California St.
Whitted, T. B., Kittredge B'ld'g. 6

Pueblo.—Freudenberger, W. K.

Silverton.—Holt, M.B.

Telluride.
Nunn, Paul N.
Ruffner, C. S. 2

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CONNECTICUT.

Ansonia.—Grower, George. G.

Bridgeport.

Crocker, E. C., 29 Harriet.
Powell, P. H., Bridgeport Brass Co. 2

Danbury.—Nock, Geo. W.

Hartford.

Corson, W. R. C., 440 Capitol Ave.
Robb, Prof. Wm. L., Trinity College.
Sachs, Jos., The Johns-Pratt Co.
Strong, F. G., Box 959. 4

Middletown.—Raub, C. B.

New London.—Storrs, H. A.

New Haven.

Everit, E. H., 641 Whitney Ave.
Heft, N. H., N.Y. N. H. & H. R R.
Sykes, H. H.
Vinton, E. S., Sargent & Co. 4

South Norwalk.—Winchester, A. E.

South Manchester.—Adams, J. L.

Wallingford.—Pierce, A. L.

Windsor.

Dopp, W. H., Eddy Electric Mfg. Co.
Heath, Harry E., " " " "
Rodgers, A. G. " " " "

3

DELAWARE.

Wilmington.—Van Trump, C. R.

DISTRICT OF COLUMBIA.

Washington.

Allen, W. C., District B'ld'g
Betts, Philander, 611 14th St., N. W.
Bliss, L. D., 614 12th St.
Byrnes, Eugene A., U. S Patent Office.
Clement, E. E., 908 G. St , N. W.
Crain, J. J., 2000 H St., N. W.
Crosby, O. T., 1417 G St.
Dieterich, F. G., 602 F St.
Fessenden, R. A., Weather Bureau.
Freeman, Frank L., 931 F St.
Hall, C. M., 7th St. & R. I. Ave.
Hopkins, N.M., 1730 I. St., N. W.
Ives, E. B., c/o War Dept
Jackson, W. S., 325 Spruce St.
Lyons, Joseph, 908 G St.
Mauro, Philip, 620 F St.
Maynard, G. C., Smithsonian Inst.
Reber, Samuel, Army Headquarters.
Roller, J. E., U. S. Navy Dept.
Rosa, E. B., Nat'l Bureau of Standards.
Russel, Edgar, War Department.
Seabrook, H. H., 1317 F. St.

Washington.—Continued.

Shea, D. W., Catholic University
Sturtevant, Charles L., Atlantic B'ldg.
Tapley, W. H., Gov. Printing Office
Town, F. E., Treasury Department.
Wolff, F. A. Jr., Columbian Univ'y.
Woodworth, G. K., 4 R St., N. W. 28

FLORIDA.

Jacksonville.

Hammatt, C. S.
Henry, G. C. 2

GEORGIA.

Atlanta.

Burkett, C. W., 321 Austell Building.
Ford, A. H., School of Tech.
Schoen, A. M., 433 Equitable B'ld'g.
Wotton, J. A., Box 543. 4

Augusta.

Edwards, Jas. P.
Moore, W. E. 2

Columbus.—Boileau, W. E.

Macon.—Nyhan, J. T.

Savannah.—Nunn Richard J., *M.D.*

IDAHO.

Dewey.—Phillips, L. A.

ILLINOIS.

Alton.

Porter, J. F., 205 Market St.

Chicago.

Abbott, W. L., 139 Adams St.
Armstrong, C. G., Fisher B'ld'g
Arnold, Bion J., 1541 Marquette B'ld'g
Arnold, W. S., Monadnock B'ld'g.
Atkins, C. G., 1110 Monadnock B'ld'g
Ayres, A. D , 171 La Salle St.
Badt, Lt. Francis B., 1504 Monadnock
Bailey, T. P., 1047 Monadnock Bldg.
Ball, W. D., 614 Rookery.
Barnett, C. P., 41st St. & Ashland Ave.
Barton, Enos M., 259 South Clinton St.
Bergenthal, V. W , 15 Monadnock Bl'k.
Boggs L. S , 1000-46 E. Van Buren St.
Brinckerhoff, H.M., 1001 Royal Ins.Bg.
Brown, C. L., 312 Fisher B'ld'g.
Carlton, W. G. 139 Adams St.
Clark, E. B., Illinois Steel Co.
Crandall, Chester D., 259 S. Clinton St.
Cravath, J. R., 1139 Monadnock Block
De Crow, C. E., 242 S. Jefferson St.
Damon, G. A., 1541 Marquette B'ld'g
de Khotinsky, A., 5520 Jefferson Ave.
Dommerque, F. J., Congress & Green Sts.
Dresser, C. A., 1808 Fisher Bldg.
Dryer, Ervin., 171 La Salle St.

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Eastman, G. N., 139 Adams St.
Eddy, H. C., Lees Building
Ferguson, L. A., 139 Adams St.
Frantzen, Arthur, 225 Dearborn St.
Gaylord, T. P., 171 La Salle St.
Gear, H. B., 139 Adams St.
Gibson, J. J., 171 La Salle St.
Goltz, Wm., 1504 Monadnock B'ld'g
Hartwell, Arthur, 171 La Salle St.
Haubrich, A M., 72 W. Jackson Boul.
Hellick, C. G., 203 Washington St.
Herdman, F. E., Otis Elevator Co.
Hibbard, Angus S. 203 Washington St.
Holbrook, F M., Old Colony Bldg.
Huguet, C. K., 752 Jackson Boulevard
Insull, Samuel, 139 Adams St.
Junkersfeld, Peter, 139 Adams St.
King, H. R., Western Electric Co.
Kinsley, Carl, Quadrangle Club.
Knox, G. W., 2329 Magnolia Ave.
Kreidler, W. A., 510 Marquette B'ld'g
Lansingh, V. R., 1610 Fisher Bldg.
Lloyd, E. W., 139 Adams St.
Lukes, G. H., 139 Adams St.
Lyman, James, Monadnock B'ld'g
Macomber, I. J., Armour Inst.
Mayer, G. M., 1581 Monadnock B'ld'g.
McBerty, F. M., Western Electric Co.
Miller, K. B., Congress & Green Sts.
Morehead, J. M., 157 Michigan Ave.
Neiler, S. G., 1409 Manhattan B'ld'g
Niesz, H. E., 139 Adams St.
Pearson, F. J., 3841 West 63d Place.
Pierce, R. H., 1409 Manhattan B'ld'g
Reichmann, F., University of Chicago.
Rideout, A. C., 101 Randolph St.
Schildhauer Edw., 139 Adams St.
Schweitzer, E. O., 667 Lincoln Ave.
Scribner, C. E , 259 So. Clinton St.
Searles, A. L., Marquette B'ld'g
Summers, Leland L., 441 Rookery
Thordarsson, C. H., 128 LaSalle Ave.
Wait, Henry H., 259 So. Clinton St.
Warner, E. P., 259 So. Clinton St.
Widdicombe, R. A., 259 S. Clinton St.
Wiler, Carl, Western Electric Co.
Wilkes, C. M., 1142 The Rookery
Woodworth, P. B., Lewis Inst.
Wray, J. G., 203 Washington St.
Zabel, M. W. 1450 Monadnock B'ld'g. 76

Kane.—Dressel, J. H.

Maywood.—Kennedy, A. P.

Oak Park.—Bentley, M. H.

Peoria—Gutmann, L.

Pullmann, Etheridge, Locke.

Quincy.—Chubbuck, H. E.

(85)

Springfield.—Lanphier, R. C.

Urbana.

Brooks, Morgan.
Browne, W. H., Jr. 2

INDIANA.

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Fort Wayne.

Barnes, Edw. A. Ft Wayne Electric Co.
Crawford, D. F., P. R. R.
Hadley, A. L., Ft. Wayne Elec. Works
Hunting, F. S., 325 W. Washington St. 4

Indianapolis.

Green, E. C., 1710 Prospect St.
Marsh, H. B., The Sanborn-Marsh Electric Co. 2

Geneva.

MacFadden, C. K.
Thayer, G. L., 2

Lafayette.

Duncan, Thomas
Esterline, J. W., Purdue University.
Goldsborough, W. E., 113 South St.
Kelsey, J. C.
Matthews, C. P., 168 Pierce St. 5

IOWA.

Ames.—Lanphear, B. S.

Des Moines.—Cunningham, E. R.

Montezuma.—Mortland, J. A.

KANSAS.

Topeka.

McVay, H. D.
Pen Dell, C. W., A. T. & S. F. Ry. 2

Wichita.—Baker, A. O.

KENTUCKY.

Louisville.

Hubley, G. W., 14th & Magazine Sts.

LOUISIANA.

New Orleans.

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Ayres, Brown, Tulane University.
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Venable, W. M., 713 Hennen Bldg. 4

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Orono.—Webb, Howard S.

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Browne, S. H., Md. Tel. B'ld'g
Ellard, John W., 220 East German St.
Hall, Clayton C., 10 South St.
Holmes, G. R, 215 No. Calvert St.
Keilholtz, P. O., Con. Trust B'ld'g.
McCay, H. K., 107 E. German St.
Morrison, J. Frank, 15 South St.
Northrup, E. F., 710 N. Howard St.
Schoolfield, F. R., 713 W. Fayette St.
Schwab, M. C. 1709 Madison Ave
Scott, J. B., 808 Maryland Trust B'ld'g
Straus, Theo., 13 W. Pratt St.
Varney, W. W., 712 N. Carey St.
Whitehead, J. B. Jr., Johns Hopk's Un.
Young, W. D., Roland Park 16

MASSACHUSETTS.

Amherst.—Barry, David

Andover.—Coleman, W. H.

Auburndale.—Blake, Francis

Boston.

Adams, A. D., Box 1377
Bailey, L. W., 8 Oliver St.
Baker, J. B., 40 Lincoln St.
Baldwin, J. C. T., 125 Milk St.
Bancroft, C. F., 14 Kilby St.
Blodgett, Geo. W., B. & A. R. R.
Blood, J. B., 10 Post Office Square.
Bullen, D. R., 200 Summer St.
Burleigh, Chas. B., 200 Summer St.
Cabot, F. E., 55 Kilby St.
Cabot, Sewall, 101 Milk St.
Childs, A. E., 23 Central St.
Codman, J. S., 31 Milk St.
Cross, Chas. R., Mass. Inst. Tech.
Davis, P. W., Elec. Stor. Bat. Co.
Doolittle, Thos. B., 125 Milk St.
Edgar, C. L., 70 State St.
Erickson, F. Wm., 280 Devonshire St.
Fish, F. P., 125 Milk St.
Ford, Wm. S., Room 73, 125 Milk St.
Garratt, A. V., 36 Whittier St.
Goddard, C. M., 55 Kilby St.
Hamilton, Jas., 53 State St.
Hayes, Hammond V., 125 Milk St.
Herrick, Charles H., 3 Head Place
Hosmer, Sidney, Ames Building
Le Clear, Gifford, 15 Exchange St.
Lee, J. C., 125 Milk St.

Boston.—Continued.

Lockwood, Thomas D., 125 Milk St.
McGrath, W. H., 93 Federal St.
Morgan, C. L., 3 Head Place.
Paine, Sidney B., 200 Summer St.
Pickernell, F. A., 125 Milk St.
Puffer, Wm. L., Mass. Inst. of Tech.
Richards, C. W., 178 Devonshire St.
Robb, Russell, 93 Federal St.
Ross, Norman N., 203 Equitable Bldg.
Smith, W. L., 360 Marlborough St.
Smith, F. B., 170 Summer St.
Spaulding, H. C, Equitable B'ld'g.
Stearns, C. K., 93 Federal St.
Stone, Charles A., 93 Federal St.
Sweetland, Ralph, 55 Kilby St.
Viehe, J. S., 103 Circuit St.
Wallace, C. F., 93 Federal St.
Warren, H. E., 36 Whittier St.
Webster, Edwin S., 93 Federal St.
Wheildon, L. B., 1027 Exchange Bldg.
Whitaker, S. E., 43 Milk St
Whitney, Henry M., 95 Milk St.
Whitney, W. R., Mass. Inst. Tech. 51

Brookline.

Bell, Louis
Fleming, J. F.
Holtzer, Chas. W. 3

Cambridge.

Adams, C. A., Jr., 13 Farrar St.
Ayer, Jas. I., Franklin & Sidney Sts.
Blackwell, H. L., 13 Little's Block.
Clark, W. E., 1400 Mass. Ave.
Whiting, S. E., 11 Ware St. 5

Cambridgeport.—Hopewell, C. F.

Danvers.—Hood, R. O.

East Saugus.—Fog, C. F.

East Somerville.—Williams C., Jr.

Fall River.—Warner, C. H.

Great Barrington.—Stanley, Wm.

Holyoke.—Winchester, S. B.

Hudson.—Lawrence, W. G.

Jamaica Plain.

Balcome, H. A.
Brophy, Wm, 17 Egleston St. 2

Lawrence.—Humphreys, C. J. R.

Lynn.

Boyer, E. E., Gen'l Electric Co.
Cox, F. P., " "
Fish, Walter C., " "
Fleming, Richard, " "
Hopkins, N. S., " "
Lemp, H. Jr., " "
Murphy, E. J., " "
Pratt, W. H., " "
Ryan, W. D. A. " "
Thomson, Elihu, " " 10

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Nantucket, *Siasconset.*—Pfund, R.

Natick.

Appleyard, A. E.
Gale, H. B. 2

Pittsfield.

Barnes, H. H.
Chesney, C. C., Stanley Electric Co.
Dodd, S. T., " "
Heitmann, E. Jr., " "
Jackson, W. B. " "
Kelly, J. F., " "
Kline, J. J., " "
Mudge, A. L., " "
Perrine, F. A. C., " "
Rushmore, D. B., " "
Thompson, E. J., " "
Tobey, H. W., " "
Truesdell, A. E., 50 Brenton Terrace.

Springfield. 13

Anderson, H. S., United E. L. Co.
Hyde, Jerome W., Wason Building
Mulligan, W. L., United Elec. Lt. Co. 3

Stockbridge.—Field, S. D.

Winchester.—Davenport, Geo. W.

Worcester.

Coghlin, J. P., 24 Pearl St.
Haskins, W. E., Am. Steel & Wire Co.
Jones, F. R., Polytechnic Inst.
Latham, H. M., Am. Steel and Wire Co.
Smith, H. B., Polytechnic Inst. 5

MICHIGAN

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Carhart, H. S.
French, Thos., Jr., 114 N. Ingalls St.
Patterson, G. W., Jr., 814 S. Univ. Av. 3

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Detroit.

Blades, Harry H., 419 Cass Ave.
Dow, Alex, 18 Washington Ave.
Field, H. G., 1203 Majestic B'ld'g
Jackson, E. D., 82 Beech St.
Livsey, J. H., 704 Chamber of Com.
Phelps, W. J.
Ray, W. D., 1201 Chamber of Com.
Stewart, R. S., 440 Jefferson Ave. 8

Grand Rapids.

Cody, L. P.
Lamb, F. J. 2

Lake Linden.—White, C. G.

Monroe.—Reilly, H. W.

Sault Ste. Marie.—Edmands, J. R.

MINNESOTA.

Minneapolis.

Burch, E. P., 1210 Guaranty Building.
Flather, J. J., 1103 Fourth St.
Pillsbury, C. L., Andrus Building.
Reid, William, Telephone Building.
Shephardson, G. D., Univ. of Minn.
Springer, F. W., Univ. of Minn. 6

St. Paul.

Gille, H. J., St. Paul Gas Light Co.
Simpson, J. M., Am. Grass Twine Co.
Zahm, A. W., Manhattan Building. 3

Willmar.—Johnson, A. C.

MISSISSIPPI.

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Vicksburg.—George, J. Z.

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Crystal City.—Bausch, F. E., Pittsburg Plate Glass Co.

Kansas City.

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Morgan, J. L., City Hall.
Richardson, R. E.
Weeks, E. R., 606 New Nelson Bldg. 4

St. Louis.

Durant, Geo. F., Telephone B'ld'g
Garrels, W. L., 3 Franklin Bk. Bldg.
Hessenbruch, G. S., 205 Union Station Terminal.
Humphrey, H. H., 1305 Chemical B'ld'g.
Klauder, R. H., 817 Wainwright Bldg.
Layman, W. A., 2017 Locust St.
Peticolas, S. G., 2017 Locust St.
Randall, J. E., 1912 Olive St.
Roper, D. W., 920 Rialto Bldg.
Rustin, Henry, World's Fair.
Schlosser, F. G., 411 No. 11th St.
Schwedtmann, F., 2017 Locust St.
Swope, Gerard, 810 Spruce St.
Wells, G. E., 817 Clarendon Ave. 14

MONTANA.

Anaconda.—Magnus, B.

Bozeman.—Williams, W. H.

Great Falls.—Morrow, John T.

Helena.—Gerry, M. H. Jr.

NEBRASKA.

Gering.—Snyder, N. M.

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Manchester.

Clough, A. L., Box 114
Smith, J. Brodie, 142 Merrimack St. 2

NEW JERSEY.

Ampere.

Bates, P. A., Crocker-Wheeler Co.
Dunn, G. S., " "
Henshaw, F. V., " "
Thompson, A. J. " "
Treat, R. B., " "
Wheeler, S. S., " " 6

Bayonne.—Chamberlain, J. C.

Bloomfield.—Wiederhold, O.

Bridgeton.—Smith, Oberlin

Camden.—Harrington, Walter E.

Cartaret.—Prosser, H. A.

East Orange.

Aylesworth J. W., 223 Midland Av.
Fliess, R. A., 44 Chestnut St.
Hammer, E. W., 18 North 22d St.
Jackson, F. E., 61 So. Grove St. 4

Elizabeth

Diehl, Philip, Diehl M'f'g Co.
Bennett, E. H., Jr., Singer M'f'g Co.
Miller, H. S., Diehl M'f'g Co.
Whiting, A. H., 4

Garwood.—Fowler, Geo. W.

Hackensack.—Uebelacker, C. F.

Harrison.

Howell, J. W.
Marshall J. T.
Page A. D. 3

Hoboken.

Brisley, E. B., Stevens Institute.
Cuntz, Johannes H., 325 Hudson St.
Ganz, A. F., Stevens Institute
Geyer, Wm. E., " "
Morton, Henry " "
ter Meer, H. C., 930 Hudson St.
Woodbury, D. C., Stevens Institute. 7

Jersey City.

Ockershausen, H. A.
Poirier, A. E., 8 Erie St.
Rushmore, S. W., 24 Morris St.
Sloan, J. R., Pullman Co., P. R. R. 4

Newark.

Billberg, C. O. C., 17 Hill St.
Bosch, Adam, Fire Alarm Telegraph.
Colby, Edward A., Lock Box 113
Farrand, Dudley, 207 Market St.
Moore, D. McF., 52 Lawrence St.
Richtberg, H. A., W. E. & M. Co. 6

New Brunswick.—Brackett. B. B.

Orange.

Edison, Thomas A.
Miller, W. H.
Upton, F. R. 3

Parlin.—Flack, J. Day.

Perth Amboy.—Brewster, W. S.

Plainfield.—McClurg, W. A.

Princeton.—Brackett, C. F.

Rahway.—Buys, Albert

Rutherford.

Brown, H. A.
Petty, Walter M.
Schwabe, W. P. 3

Short Hills.—Riker, A. L.

Somerville.—Tait, F. M.

South Orange.—Delany, P. B.

Stewartsville.—Darling, E. A.

Trenton.

Horn, H. J., 36 W. State St.
Newbury, F. J., Roeblings Co.
Roebling, F. W., Roeblings Co. 3

Waverly Park.—Weston, Edward.

Westfield.

Mansfield, R. H., Jr.
Smith, F. W., 2 Charles St. 2

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Mesilla Park.—Brady, F. W.

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Judson, W. P., State House.
McElroy, James F., 131 Lake Ave.
Miller, Wm. C., 3 South Hawk St.
Van Buren, Gurdon C., 62 So. Hawk St.
Wilder, H. W., H. R. Telephone Co. 6

Astoria.—Folk, F. J.

Auburn.—Case, W. E.

Belmont.—Gorton, Charles

Bronxville.

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Kebler, J. L.
Leonard, H. Ward 3

Brooklyn.

Ashe, S. W., Polytechnic Institute.
Braun, C. E., 223 Madison St.

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Brown, Benjamin, 381 Sackett St.
Brown, R. G., 158 Montague St.
Chapman, A. W., 160 Hicks St.
Dassori, F. H., 81 Willoughby St.
Degen, L., 324 Stuyvesant Ave.
Edmands, S. S., Pratt Institute.
Ekstrand, C., N. 6th St. & Kent Ave.
Ferris, R. M., Jr., 81 Willoughby St.
Gherardi, B. Jr., 81 Willoughby St.
Hall, H. C., Polytechnic Institute.
Holbrow, H. L., U. S. Navy Yard.
Hutchinson, R. W. Jr., Polytech. Inst.
Leitch, H. W., 373 Madison St.
Leslie, E. A., 360 Pearl St.
Martin, F., U. S. Navy Yard.
Martin, J., " "
Mason, Hobart, 432 Greene Ave.
Morrill, E. F., 81 Willoughby St.
Mosscrop, W. A., 47 Brevoort Pl.
Ormsbee, A. F., 81 Willoughby St.
Parker, L. R., 345 State St.
Peck, E. F., 360 Pearl St.
Powelson, W. V. N., U. S. Navy Yard.
Reilly, John C., 81 Willoughby St.
Sargent, W. D., 81 Willoughby St.
Shaw, A. N., 116 Front St.
Sheldon, Samuel, Polytech. Institute.
Spoehrer, H., U. S. Navy Yard.
Stevens, Cabot, 360 Pearl St.
Thomas, A. C., 81 Willoughby St.
Warren, A. K., 2075 Broadway.
Wolcott, T., 329 Clinton St.
Woodward, F. S., 265 Prospect Pl. 36

Buffalo.

Alverson, H. B., 40 Court St.
Edmonston, E. D., 401 Delaware Ave.
Gifford, C. E., Caton's College.
Grissinger, Elwood, 40 Court St.
Howe, W. K., Carroll and Wells Sts.
Huntley, C. R., 40 Court St.
McCarthy, E. D., 45 No. Division St.
Meadows, H. G., 109 White B'ld'g.
Offinger, M. H., 544 Plymouth Ave.
Perkins, Frank C., 126 Erie Co. Bank.
Pope, H. W., 14 W. Seneca St.
Sowers, D. W., 240 W. Utica St.
Whittemore, G. W. 13

Dobbs Ferry.—Judson, H. C.

Elmira.

Cole, W. W., Realty B'ld'g.
Wolverton, B.C., N.Y. & Pa.T. & T.Co.

Fulton.—Emerick, L. W. 2

Ithaca.

Bedell, Fred. Dr., Cornell University.
McAllister, A. S., " "
Nichols, E. L., " "
Ryan, H. J., " "
Yamazaki, Shiro, " " 5

Larchmont.—Neilson, John

Lockport.—Kenan, W. R., Jr.

Mt. Vernon.

Tyndall, C. H.
Whitney, C. E., 553 South 6th Ave. 2

New Brighton.

Johnson, W. McA.
Libby, S. B. 2

Newburgh.

Boynton, E. C.
Hewitt, C. E. 2

New York City.

Abbott, A. V., 26 Cortlandt St.
Abbott, Henry, 9 Maiden Lane
Adams, E. K., 455 Madison Ave.
Adler, A. A., 123 Liberty St
Agnew, C. R., 18 William St.
Albright, H. F., 463 West St.
Alexander, Harry, 25 W. 33d St.
Allen, A. P., 15 Dey St.
Andrews, W. C. 120 Liberty St.
Anthony, J. S., 44 Broad St.
Anthony, W. A., Cooper Union
Archer, G. F., 156 Madison Ave.
Arnold, C. H., 18 Cortlandt St.
Ashley, F. M., 108 Fulton St.
Atkins, H. B., 22 William St.
Atkinson, W. S., 127 Fifth Ave.
Atwood, G. F., 463 West St.
Aylmer-Small, C. S., Waldorf-Astoria.
Baillard, E. V., Fox Building.
Baker, W. E., 170 Broadway.
Baldwin, A. de V., 39 Cortlandt St.
Ball, H. P., 572 First Ave.
Bamber, W. C., 13 Park Row.
Bangs, C. R. 15 Dey St.
Banks, W. C., 13 Laight St
Baron, Max D., 125 E. 23rd St.
Barr, J. B., 44 Broad St.
Barstow, W. S., 11 Broadway.
Batchelor, C., 52 Broadway.
Bates, F. C., 44 Broad St.
Bates, J. H., 57 Duane St.
Baylis, R. N., 140 Washington St.
Bayne, H., Columbia University.
Beaumont, C. W., 52 Broadway.
Bell, A. C., 197 Wooster St.
Bell, O. A., 463 West St.
Bellman, J. J., 149 Broadway.
Bennett, J. C., 44 Broad St.
Bennett, W. S., 5 Union Square, West.
Bentley, E. M., 5 Beekman St.
Bethell, U. N., 15 Dey St.
Betts, H. D., 141 Broadway
Bicknell, D. E., 57 Bethune St.
Bijur, Jos., 210 Centre St.
Birdsall, E. T., 26 Cortlandt St.
Black, C. N., 149 Broadway.
Black, H. D., 39 Cortlandt
Blackall, F. S., 39 Cortlandt St.
Blake, Henry W., 120 Liberty St.
Blake, T. W., 1955 Park Ave.
Bliss, W. L., 16 Exchange St.

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Bohm, Ludwig K., 320 Broadway.
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Bradley, C. S., 44 Broad St.
Brady, N. F., 57 Duane St.
Briesen, H. V., 22 Thames St.
Brixey, W. R., 203 Broadway.
Brown, W. D., 61 Elm St.
Buckingham, Chas. L., 195 Broadway
Bunce, Theo. D. Jr., 239 E. 27th St.
Burdick, I. E., 256 Broadway
Burnett, Douglass, 55 Duane St.
Burroughs, H. S., 20 Nassau St.
Burton, Paul G., 463 West St.
Byrns, R. A., 20 Broad St.
Cahoon, Jas. B., 35 Nassau St.
Caldwell, Edw., 112 Liberty St.
Caldwell, E. W., 315 Fifth Ave.
Canfield, M. E., 57 Bethune St.
Carichoff, E. R. 52 Broadway.
Carpenter, H. C., 15 Dey St.
Carty, J. J., 15 Dey St.
Chandler, C. F., Columbia Univ.
Chester, M. E., 463 West St.
Child, C. T., 13 Park Row.
Clark, C. M., 20-22 Broad St.
Clark, Ernest P., 19th St. & 6th Ave.
Clark, F. G., 96th St. and 1st Ave.
Clark, Le Roy, Jr., 229 W. 28th St.
Clark, W. J., 44 Broad St.
Clarke, Charles L., 31 Nassau St.
Coffin, Chas. A., 44 Broad St.
Coho, H. B., 149 Broadway
Collett, S. D., 136 Liberty St.
Compton, A. G., 17 Lexington Ave.
Comstock, L. K., 137 Broadway.
Condict, G. H., Electric Vehicle Co.
Cornell, C. L., 136 Liberty St.
Cornell, J. B, 136 Liberty St.
Cosby, F. C., 120 Broadway.
Cowen, J. B., 572 1st Ave.
Crane, W. F. D., 31 Nassau St.
Crocker, Francis B., Columbia Univ.
Crossman, Gilbert, 463 West St.
Crozier, A. B., 45th St & 1st Ave.
Cunningham, R. H., Columbia Univ.
Cushing, H. C., Jr., 39 Cortlandt St.
Cuttriss, Chas., 20 Broad St.
Davidson, E. C., 141 Broadway
Davis, Chas. H., 25 Broad St.
Davis, Joseph P., 113 W. 38th St.
Davis, Minor M., 253 Broadway
Decker, E. P., 26 Cortlandt St.
Dickerson. E. N., 141 Broadway
Dixon James, 80 Broadway.
Doherty, H. L., 40 Wall St.
Donaldson, Wm. W., 25 W. 33d St.
Doremus, C. A., 59 W. 51st St.
Doud, C. H., Columbia Univ.
Dowie, Horace, 26 Cortlandt St.
Dressler, Chas. E., 17 Lexington Ave.
DuBois, Tuthill, 19 Park Place.

New York City.—Continued.

Duncan, J. D. E., 31 Nassau St.
Duncan, Louis, 71 Broadway
Dunn, C. E., Park Row B'ld'g.
Durant, Edward, Ward's Island.
Dyer, R. N., 31 Nassau St.
Edwards, C. V., 220 Broadway
Ellinger, Edgar, 137 Broadway.
Farnsworth, A. J., 22 Thames St.
Field, C. J., 133 West 38th St.
Floy, Henry, 220 Broadway
Forbes, Francis, 32 Nassau St.
Ford, F. R., 149 Broadway
Gallatin, A. R., 58 W. 55th St.
Gilman, F. L., 463 West St.
Goldmark, Chas. J., 66 New St.
Gordon, Reginald, 315 West 71st St.
Gotshall, W. C., 76 William St.
Granbery, J. H., 32 Park Place.
Grant, O. R., Columbia Univ.
Gray, C. D., 29 Broadway.
Gray, E. W. T., 120 Broadway.
Griffen, J. D., 25 Broad St.
Griffin, E., 44 Broad St.
Guy, Geo. H., 114 Liberty St.
Hadaway, W. S. Jr. 107 Liberty St.
Hadley, F. W., 26 CortlandtSt.
Hall, Edw. J., 15 Dey St.
Hall, F. A., 115 W. 47th St.
Hallberg, J. H., 572 First Ave.
Hamilton, Geo. A., 463 West St.
Hamerschlag, A. A., 41 Liberty St.
Hammer, W. J., 922 Havemeyer Bg.
Hanchett, Geo. T., 123 Liberty St.
Harding, H. McL. 20 Broad St.
Harris, G. A., 10 Wall St.
Hatzel, J. C., 114 Fifth Ave.
Hayes, Harry E., 22 Thames St.
Hedenberg, W. L., 136 Liberty St.
Hemingway, A. F., 463 West St.
Henry, Ira W., 229 West 28th St.
Henderson, Alex., 527 W. 34th St.
Herrick, Albert B., 120 Liberty St.
Herzog, Dr. F. Benedict, 51 W. 24th St.
Hewitt, P. C., 11 Lexington Ave.
Higgins, Edward E., 32 Waverly Place.
Hildburgh, W. L., Hotel Normandie
Hill, George, 100 Broadway.
Hill, G. Henry, 527 W. 34th St.
Hill, N. S. Jr., 100 William St.
Hodge, Charles, 120 Broadway.
Hoffmann, B., 15 Dey St.
Holmes, Franklin S., 108 Fulton St.
Hoopes, Maurice, 29 Broadway.
Howell, W. S., 14 Jay St.
Howson, Hubert, 38 Park Row
Hoxie, G. L., 26 Cortlandt St.
Hubbard, A. S., 25 W. 33d St.
Hubbard, W. C., 120 Broadway.
Hunt, A. L., 203 Broadway
Hutchinson, Cary T., 56 Pine St.
Hyde, J. E. H., 120 Broadway.
Idell, Frank E., Havemeyer Building.

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New York City.—Continued.

Insull, M. J., 572 1st Ave.
Jaeger, C. L., 132 Mulberry St.
Jannus, F., 141 Broadway
Jenks, William J., 120 Broadway.
Johnston, T. J., 66 Broadway.
Johnston, W. J., 261 Broadway.
Jones, Francis W., 253 Broadway
Keefer, E. S., 463 West St.
Keith, N. S., 95 Liberty St.
Kennedy, J. J., 52 Broadway.
Ker, W. W., 36 Stuyvesant St.
King, V. C., Jr., 517 West St.
Kinsman, F. E., 95 Liberty St.
Kintner, C. J., 45 Broadway.
Knowles, E. R., 136 Liberty St.
Knox, C. E., 76 William St.
Knudson, A. A., 32 Nassau St.
Lamb, Richard, 136 Liberty St.
Langton, Jno., 72 Trinity Pl.
Lanman, Wm. H., 120 Broadway
Lardner, H. A., 29 Broadway.
La Roche, F. A., 652 Hudson St.
Lawrence, W. H., 49 W. 26th St.
Ledoux, A. R., 99 John St.
Lieb, J. W., Jr., 57 Duane St.
Lilibridge, R. D., 20 Broad St.
Livingston, J. Jr., 13 Park Row
Lloyd, Robert McA., 100 Broadway
Loewenthal, M., 11 Broadway.
Lohmann, R. W., 711 Transit B'l'dg.
Louis, O. T., 340 E. 119th St.
Lowson, David, 1721 Park Row B'ld'g.
Lowther, C. M., 36 Riverside Drive.
Lozier, R. T. E., 220 Broadway
Lundell, Robert, 527 W. 34th St.
Lundie, John, 52 Broadway
Lyford, O. S., Jr. 100 Broadway.
Lyman, C. W., 30 Broad St.
Lyndon, L., Park Row Bldg.
MacGregor, W. H., 120 Broadway.
Mahoney, J. J., 44 Broad St.
Mailloux, C. O., 76 William St.
Marks, L. B., 687 Broadway
Marsh, C. J., 56 Liberty St.
Martin T. Commerford, 114 Liberty St.
Marvin, H. N., 841 Broadway.
Maver, William, Jr., 120 Liberty St.
Mayer, M. M., 216, Centre St.
McClure, W. J., 259 W. 52dSt.
McGraw, James H., 114 Liberty St.
McLain, R. C., 21 Park Row.
McLimont, A. W., 141 Broadway.
Merrill, E. A., 26 Cortlandt St.
Mershon, R. D., 621 Broadway
Meyer, Julius, 115 Broadway
Miller, A. J., 463 West St.
Miller, D. D., 120 Broadway.
Molé, H. E., 74th St. and East River.
Monrath, Gustave, 7 E. 42d St.
Mora, M. L. 44 Broad St.
Morley, E. L., 114 5th Ave.
Morrison, W. J., Jr., 60 Broadway.
Moses, P. R., 35 Nassau St.
Mullin, E. H., 44 Broad St.

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New York City.—Continued

Murphy, G. R., 100 Broadway.
Murray, T. E., 55 Duane St.
Muschenheim, F. A., 463 West St.
Neurath, M. M., 165 Broadway.
Nicholson, S. L., 120 Broadway.
Nimis, A.A., N.E.cor.82d St.& Lex. Av.
Noll, Augustus, 8 E. 17th St.
O'Brien, A. D., 15 Dey St.
O'Donovan, L. J., Columbia University
Osterberg, Max, 11 Broadway
Paine, F. B. H., 120 Broadway
Parker, H. C., Columbia Univ.
Parmly, C. Howard, 17 Lexington Ave.
Parsell, H. V. 129 W. 31st St.
Parshall, A., 44 Broad St.
Parsons, I. D., Columbia University.
Pattison, Frank A. 111 Broadway
Pearson, F. S., 621 Broadway
Pedersen, F. M. 17 Lexington Ave.
Phillips, E. L., 26 Cortlandt St
Poole, Cecil P., 114 Liberty St.
Pope, Ralph W., 95 Liberty St.
Porter, H. H., Jr., 31 Nassau St.
Potter, H. N., 510 West 23d St.
Powell, E. B., 55 Duane St.
Price, C. W., 13 Park Row
Prince, J. L., 57 Duane St.
Proctor, T. L., 39 Cortlandt St.
Putnin, Michael I., Columbia Univ.
Rae, Frank B., 52 Broadway.
Reckenzaun, F., 1 Broadway.
von Recklinghausen M., 510 W. 23d St.
Reed, H. A., 420 E. 25th St.
Reed, H. D., 420 E. 25th St.
Reid, Thorburn, 136 Liberty St.
Rennard, J. C., 15 Dey St.
Rice, A. L., 12 W. 31st St.
Ries, E. E., 116 Nassau St.
Ripley, W. H., 24 Murray St.
Roberson, O. R., 195 Broadway
Robinson, F. G., 621 Broadway
Rogers, Nelson, 510 W. 23rd St.
Roller, F. W., 203 Broadway
Rosenbaum, Wm. A., 140 Nassau St.
Rosenberg, E. M., 138 W. 85th St.
Rouquette, W. F. B., 47 Dey St.
Ruckgaber, A. F., 13 Park Row.
Rugg, W. S., 120 Broadway.
Ryerson, W. N., 74th St. & East River.
Ryder, M. P., 140th St. and R ver Ave.
Sage, F. B., 123 Liberty St.
Salter, T. F., 463 West St.
Sanborn, F. N., 29 Wall St.
Sanderson, E. N., 31 Nassau St.
Sanville, H. F., 15 Cortlandt St.
Saxelby, F., 220 Broadway.
Scheffler, F. A., 9 Dey St.
Schmidt, Lambert, 325 Broadway.
Schreiter, Heinr., 20 Nassau St.
Schroeder, Henry, 57 Duane St.
Scudder, H. Jr., 21 E. 22d St.
See, A. B., 220 Broadway.
Serrell, Lemuel Wm. 99 Cedar St.
Sever, Geo. F., Columbia Univer.

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New York City.—Continued.

Sharp, C. H., 14 Jay St.
Sherwood, E. F., 18th St. & Irving Pl.
Simpson, A. B., 54 M. Lane
Sinclair, H. A., 35 South William St.
Skirrow, J. F., 253 Broadway
Slade, A. J., Grand Central Station.
Slater, F. R., 32 Park Place.
Smith, F. S., 510 W. 23d St.
Smith, I. B., 180 Broadway.
Smith, Irving W., 420 E. 25th St.
Smith, Jesse M., 220 Broadway
Smith, T. Jarrard, 98 Fulton St.
Smith, W. N., 26 Cortlandt St.
Spellmire, W. B., 220 Broadway.
Spencer, C. J., Grand Central Station.
Sprague, Frank J., 527 W. 34th St.
Steele, W. D., 26 Cortlandt St.
Stern, P. K., 130 Fulton St.
Stieringer, Luther, 129 Greenwich St.
Stillwell, L. B., 13 Park Row.
Stockbridge, Geo. H., 120 Broadway
Stott, H. G., 74th St. and East River.
Stout, J. S., Jr., 55 Duane St.
Strauss, H. A., Park Row B'ld'g.
Strong, J. R., 35 So. William St.
Taylor, A., 100 Broadway
Terry, A. S., 403 West St.
Terry, Chas. A., 120 Broadway
Tesla, Nikola, 16 E. Houston St,
Thomas, R. McK. 141 Broadway
Thompson, Edward P., 156 Fifth Ave.
Thomson, G. A., 136 Liberty St.
Thurber, H. F., 15 Dey St.
Torchio, P., 53 Duane St.
Townley, C., 120 Broadway.
Townsend, Henry C., 141 Broadway
Townsend, Fitzhugh, Columbia Univ.
Treadwell, A., 100 Broadway
Tyng, F. E., 164 W. 27th St.
Vail, Theo. N., 26 Cortlandt St.
VanDeventer, C., 71 Broadway.
Vansize, William B., 253 Broadway
Van Wyck, P. V. R., Jr., 15 Dey St.
Vreeland, Frederick K., Box 1877.
Waddell, M., 135 Broadway.
Wagner, H. A., Times Building.
Waldo, Leonard, 49 Wall Street.
Walker, F. W., 15 Dey St.
Waterman, F. N., 150 Nassau St.
Waterman, M. B., 55 Duane St.
Waters, E. G., 44 Broad St.
Weaver, W. D., 114 Liberty St.
Webb, Herbert Laws, 15 Dey St.
Webster, W. C., 120 Broadway
Wells, W. F., 55 Duane St.
Wellman, H. R. 572 First Ave.
Weston, S. F., 1123 Broadway.
Wetzler, Joseph, 240 W. 23rd St.
Weymouth, T. R., 40 Wall St.
White, F. J. Columbia University.
White, J. G., 29 Broadway
Whitmore, W. G., 44 Broad St.
Wightman, M. J., 150 Nassau St.

New York City.—Continued.

Wiener, A. E., 240 W. 23rd St.
Wiley, Geo. L., 56 Liberty St.
Wiley, Wm. H., 43 E. 19th St.
Williams, A. 57 Duane St.
Willyoung, E. G., 11 Frankfort St.
Wilson, C. H., 15 Dey St.
Wilson, Fremont, 80 Broadway.
Wilson, R. L., 208 E. 74th St.
Wilson, H. C., 49 Wall St.
Wintner, L., 572 First Ave.
Wintringham, J. P., 36 Pine St.
Woolf, Albert 415 Lexington Ave.
Yarnall, V. H., 302 Broadway.
Yorke, G. M., 15 Dey St.
Young, C. G., 29 Broadway.
Young, Chas. L., 120 Broadway.
Zalinski, Capt. E. L., 7 W. 43d St. 386
Official Stenographer.
Ryan, R. W., 150 Nassau St.

Niagara Falls.

Acheson, E. G., Carborundum Co.
Adams, W. L., Gluck B'ld'g.
Barton, P. P., N. F. Power Co.
Benoliel, S. D., Roberts Chemical Co
Buck, H. W., 123 Buffalo Ave.
Deeds, E. A., The Natural Food Co.
Gibboney, W. K., N. F. Power Co.
Johnson, W. C., N. F. Hydraulic Co.
Lincoln, P. M., Cataract Const. Co
Lovejoy, D. R., Cataract Chemical Co.
Price, E. F., Union Carbide Co. 11

Ogdensburg.—Jones, M. E.

Olean.—Ramsey, H. N.,

Pelham Manor.—Gilliland, E. T.

Potsdam.

Aldrich, W. S.
Dates, H. B. 2

Poughkeepsie —Sheldon, E. E.

Rhinecliff.—Philbrick, B. W.

Rochester.

Barnes, C. R.
Redman, G. A. 2

Schenectady.

Andrews, W. S., General Electric Co
Armstrong, A. H., " " "
Averrett, A., " " "
Badeau, I. F., " " "
Berg, E. J., " " "
Berg, Eskil, " " "
Blackwell, F. O., " " "
Carter, F. W., " " "
Clark, W. S., " " "
Corey, F. B., " " "
Davis, A. G., " " "
Davis, W. J. Jr., " " "
Dempster, Thos., " " "
Eddy, H. T., Union College.
Emmet, W. L. R., General Electric Co.

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Schenectady.—Continued.

Ely, W. G. Jr., General Electric Co.
Ferguson, S., " " "
Haskins, Caryl D., " " "
Hawks, H. D., " " "
Hewlett, Edw. M., " " "
Hillman, H. W., " " "
Jenks, A. P., " " "
Kellogg, J. W. " " "
Kruesi, A. H., " " "
Lovejoy, J. R., " " "
Marburg, L. C., " " "
McClenathen, Robt., " " "
Moody, V. D., 427 Smith St.
Moore, J. P., General Electric Co.
Oudin, M. A., " " "
Oolgaidt, J. J., " " "
Potter, W. B., " " "
Price, N. I., " " "
Read, R. H., " " "
Reist, H. G., " " "
Rice, E Wilbur, Jr., " " "
Rice, M. P., " " "
Rohrer, Albert, L, " " "
Sage, Darrow. " " "
Sargent, H. R., " " "
Sawyer, W. H., " " "
Slichter, W. I. " " "
Soren, T. N., " " "
Stebbins, Theodore " " "
Steinmetz, C. P., " " "
Wagoner, P. D., " " "
Wirt, H. C., " " "
Woodbridge, J. E., " " "

49

Stapleton.—Hunt, C. W.

Syracuse.

Archbold, Wm. K., University B'ld'g.
Brady, Paul T.
Graham, W. P.
Land, Frank, 102 Highland Ave.
Noxon, C. P. L., 500 E. Water St. 5

Tarrytown.—Crehore, A. C.

Tompkinsville.—Gregg, T. H.

Troy.—Bernard, Edgar G.

Utica.—Nicholson, W. W.

West New Brighton.

Marshall, Cloyd.

Yonkers.

Cosgrove, J. F., 38 St. Andrews Place.
Ihlder, John D., Otis Elevator Co.
Scidmore, F. L., Otis Elevator Co. 3

NORTH CAROLINA.

Biltmore.—Waddell, C. E.

Charlotte.

Sampson, F. D.
Smith, S. J, 40 So. Tryon St. 2

Cronly.—Van Dyck, W. V. B.

Greensboro.—Pirtle, Claiborne.

New London.—Frank, G. W.

Winston-Salem.—Barr, F. A.

OHIO.

Akron.—Shaw, E. C.

Cincinnati.

Baldwin, B. L., 73 Perin B'ld'g
Behrend, B. A., *Norwood.*
Bogen, L. E., Univ. of Cincinnati.
Bolles, F. G., Bullock & Wagner Co.
Cooper, William.
Creaghead, Thos. J., 802 Plum St.
Hafer, Geo. Jr., Cinc. Gas Co.
Hopton, Wm. E., 109 East 5th St.
Kerr, S. R., 610 Baymiller St.
Lilley, L. G., Cor. 3d & Walnut
Middleton, A. C., 420 W. 4th St.
Pomeroy, W. D.
Reno, C. S., 610 Baymiller St.
Rodgers, H. S., 420 W. 4th St.
White, W. F., 109 E. 5th St. 15

Cleveland.

Ambler, Wm., 76 Lincoln Ave.
Amstutz, N. S., 716 Caxton B'ld'g.
Brush, Chas. F., 453 The Arcade.
Canfield, Milton C., 48 Greymont St.
Cook, E. J., 96 Commonwealth Ave.
Cowles, Alfred H., 361 Arcade.
Eyre, M. K., Buckeye Elec. Co.
Harter, Bret., Electrical Building.
Hoag, G. M., 113 City Hall.
Lindsay, Robert. 717 Cuyahoga B'ld'g
Roberts, E. P., Electric Building.
Sperry, E. A., 855 Case Ave.
Sturdevant, C. R., 603 Electrical B'ld'g.
Wallau, H. L., 711 The Cuyahoga.
Wason, Chas. W., 2069 Euclid Ave. 115

Columbus.

Caldwell, F. C., State University.
Fish, F. A., " "
Thomas, B. F., " "
White, L. G. 4

Dayton.

Leeds. Norman.
Thresher, A. A. 2

East Liverpool.—Healy, L. W.

Lorain.—Hines, C. H.

Norwood.—Kerr, S. B.

Piqua.—Lorimer, G. W.

Ravenna.—Estes, O. A.

Salem.—Davis, Delamore L.

Sandusky.—Nesbit, J. N. G.

Springfield.

Conklin, O. F.
Zurfluh, W. N. 2

Toledo.—Bechtel, E. J.

Youngstown.—Morgan, Godfrey.

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OREGON.

Portland.

Anson, F. R., 355 Salmon St.
Babson, A. C., Worcester B'ld'g.
Cheney, W. C., Chamber of Commerce
Mitchell, Sidney Z., Fleischner B'ld'g 4

PENNSYLVANIA.

Allegheny.—Kintner, S. M.

Altoona.

Dudley, C. B.
Elmer, Wm. Jr.
Gough, H. E., 1415 11th St. 3

Braddock.—Maccoun, A. E.

Chester.—Tidd, G. N.

Duquesne.—Friedlander E.

East Pittsburg.

Auel, Carl B.
Gibson, G. H., Westinghouse Cos. 2

Harrisburg.—Best. A. T.

Hokendauqua.—Thomas, J. W.

Irwin.—Miles, J. W.

Johnstown.—Parkhurst, C. W.

Lancaster.—Kershner, J. E.

Munhall.—Dinkey, A. C.

Overbrook.—Lafore, J. A.

Palmerton.—Bull, R. W.

Phœnixville.—Perot, L. Knowles.

Philadelphia.

Biddle, J. G., Stephen Girard B'ld'g.
Blanchard, C. M., Union League.
Blizard, C., 19th St., & Allegheny Ave.
Bolan, T. V., 214 S. 11th.
Braddell, Alfred E., 316 Walnut St.
Bragg, Chas. A., Land Title B'ld'g
Coles, E. P., 214 S. 11th St.
Collins, A. F., 132 S. 6th St.
Cumner, A. B., 251 S. 12th St.
Cutler, J. E., 26 South 15th St.
Darlington, F. W., 1120 R.E.Trust Co.
Drysdale, W. A., Hale B'ld'g
Eglin, J. M., 10th and Sansom Sts.
Eglin, W. C. L., Cor. 10th & Sansom.
Ehret, C D., 1011 Chestnut St.
Eutz, J. B., 19th St. & Allegheny Ave.
Firth, W. E., Nicetown
Foster, H. A., 650 Bullitt Bldg.
Gallaher. E. B., Drexel Bldg.
Gharky, W.D., 2374 Park Ave.
Hall, J. L., 608 N. American B'ld'g.
Hartman, H. T., 1406 Land Title Bg.
Heany, J. A., 904 Quarry St.
Hering, Carl, 929 Chestnut St.
Hewitt, Chas , 809 Spruce St.
Hodge, W. B., 1010 Chestnut St.
Hodges, W. L., Keystone Telephone.
Houston, E. J., 1203 Crozer B'ld'g.

Philadelphia.—Continued.

Hunter, Rudolph M., 926 Walnut St.
James, H. D., 421 Chestnut St.
Kennelly, A. E., 218 S. 4th St
Leeds, M. E., 259 No. Broad St.
Levis, Minford, 36 North 4th St.
Lloyd, Herbert, 19th & Allegheny Ave.
Mansfield, A. N., 11th and Filbert Sts.
Marks, W. D., The Art Club.
Patton, P. I., 1026 Filbert St.
Pike, C. W., 112 N. 12th St.
Reed, C. J., 3313 N. 16th St.
Rowland, A. J., Drexel Inst.
Satherberg, C. H., Nicetown
Scott, W. M., 108 W. Johnson
Smith, T. C., 512 Stephen Girard Blg.
Smith, W. E., Nicetown.
Smith, W. F., Un. Gas. Imp. Co.
Spencer, Paul, Broad & Arch
Spencer, Theo., 11th and Filbert Sts.
Stakes, D. F., Germantown.
Stanton, C. H., 1517 Walnut St.
Stevens, J. F. 9th St. & Montgomery Av.
Stitzer, A. B., Union Traction Co.
Toerring, C. J., 1035 Ridge Ave.
Walmsley, W. N., 1002 Harrison Bldg.
Winand, P A. N., 3200 Arch St.
Wise, J. S., Jr., 2023 Mt. Vernon St. 55

Pittsburg.

Austin, S. B., 3912 Fifth Ave.
Beebe, M. C., Amber Club.
Bennett, Edward, Nernst Lamp Co.
Blakemore, M. N., Westing. E.&M.Co.
Chubbuck, L. B., W. E. & M. Co.
Converse, V. G., 15th St. & Liberty Av.
Davis, H. P., Westinghouse E & M.Co.
Dick, W. A., West'house E. & M. Co.
Dunlap, W. K., West'house E.& M. Co.
Dusinberre, G. B., W. E. & M. Co.
Erwin, F. B., West'house E. & M. Co.
Fisher, H. W. Standard Und. Cable
Hanks, Marshall W., Nernst Lamp Co.
Hartwell, Arthur, W. E. & M. Co.
Hill, E. R., Westinghouse E. & M. Co.
Hommel, L., 618 Westinghouse B'ld'g.
Keller, E. E., West'house Machine Co.
Kier, S. M., " E. & M. "
Lange, Philip A., " Machine "
Maxim, H. P., " E. & M. "
Miller, G. E , " " "
Merrill, J. L., Park B'ld'g.
Newman, F. J., W. E. & M. Co.
Nichols, L. C.
Osborne, L. A., West'house E.&M. Co.
O'Sullivan, M. J., Sylvan Ave.
Peck, J. S., Westinghouse E. & M. Co.
Rice, Calvin W., Nernst Lamp Co.
Rockwood, D. C., W'house E. & M. Co.
Scott, Chas F. " " "
Skinner, C. E., " " "
Storer, N. W., " " "

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Pittsburg.—Continued.

Stuart, H. R., West'house E. &. M. Co.
Stutz, C. C., Carnegie Building.
Taylor, F. H., West'house E. & M. C.
Temple. W. C., Bank of Commerce Bg.
Thomas, Percy H., W. E. & M. Co.
Tingley, E. M., W. E. & M. Co.
Uhlenhaut F Jr. Times Building.
VanVleet, R. M., Westing.E. & M.Co.
Walker, M les, W. E. & M. Co
Whiteside W. H., East Pittsburg, Pa.
Winslow, G. H., 339 Fifth Ave.
Wurts, A. J., Nernst LampCo. 44

Reading.—

Brown, E. E.
Brown, J. Stanford, Carpenter Steel Co.
Klinck, J. H., 5 So. 9th St. 3

Rochester.—Sage, H. J.

Scranton.

Elias, A. B., 1310 Washington St.
Webb, H. S., 1416 Monsey Ave. 2

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